The Istanbul Museum for theHistory of Science and Technology in Islam

(An Overview)

Science and Technology
in Islam

I

SCIENCE AND TECHNOLOGY IN ISLAM

VOLUME I

Introduction to the history of Arabic-Islamic sciences

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2010

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an der Johann Wolfgang Goethe-Universität

Frankfurt am Main

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PREFACE

At the time of the Romantic movement, when, under the impact of the newly established periodization that did not do justice to historical facts, there prevailed a biased view of the Renaissance and a negation of the achievements of the Middle Ages, Jean-Jacques Sédillot and his son Louis-Amélie published in 1834 the French translation of the manuscript preserved in Paris of the monumental Arabic work by Abu l-Ḥasan al-Marrākušī (7th/13th c) on applied astronomy and astronomical instruments.[1] This was followed ten years later by an admirable study of al-Marrākušī's book by Sédillot junior.[2] No doubt, men like Johann Gottfried Herder (1744-1803), Johann Wolfgang von Goethe (1749-1832), Kurt Sprengel (1766-1833), or Alexander von Humboldt (1769-1859), had previously given due credit — in the spirit of Humanism — to the Muslims or Arabs for their achievements in the history of science. Yet for decades Sédillot and his son fought for a more just approach by the scholarly world towards the achievements of the Arabic-Islamic world, even though this was resented by their academic colleagues and by the French Academy.

By a happy coincidence, the battle fought by the two Sédillots was supported by the work of the indefatigable scholar Joseph-Toussaint Reinaud (1795-1867). Produced with no less creativity and conviction, Reinaud's oeuvre dealt with the areas of geography,[3] Islamic archaeology[4] and the technology of warfare.[5] In one of his publications, he gave meaningful expression to the concept of the unity of the history of science in the following words:[6] "Chance does not play such an important role in the progress of the technical sciences and the arts. In all its discoveries, humanity moves at an even pace, step by step, not by leaps and bounds. It does not always march ahead with the same speed, but its [**viii**] progress is continuous. Man

[1] *Traité des instruments astronomiques des Arabes*, 2 vols, Paris 1834-1835 (reprint Frankfurt 1998, Islamic Mathematics and Astronomy, vol. 41).

[2] *Mémoire sur les instruments astronomiques des Arabes*, Paris 1844 (reprint in: Islamic Mathematics and Astronomy, vol. 42, pp. 45-312).

[3] Among Reinaud's numerous publications in this area, his *Introduction générale à la géographie des Orientaux* had an especial impact on the historiography of geography; it appeared as the introductory volume to his translation of the geographical work of Abu l-Fidāʾ (*Géographie d'Aboulféda*, 2 vols., Paris 1848, 1883; reprint Frankfurt 1998 as *Islamic Geography*, vols. 277-278).

[4] *Monumens arabes, persans et turcs du cabinet de M. le Duc de Blacas*, 2 vols., Paris 1828.

[5] In this area, mention may be made of the study produced in collaboration with Ildephonse Favé: *Du feu grégeois. Des feux de guerre et des origines de la poudre à canon*, Paris 1845 (reprint Frankfurt 2002, Natural Sciences in Islam, vol. 87).

[6] J.-T. Reinaud and I. Favé, *Du feu grégeois*, op. cit., p. 2.

does not invent, he deduces. If we take any area of human knowledge, its history, that is to say the history of its progress, should form an uninterrupted chain; the factual history provides us with parts of this chain, and our research must consist in finding the lost links so that we can join one part with the other."

While Ernest Renan (1823-1892) propounded in his *Averroès et l'Averroïsme*, which appeared in 1853, an entirely new outlook on the reception of Arabic philosophy in Europe — an outlook that is surprising for the historian of science —, an extra-ordinarily gifted young German scholar, who studied in Paris with Alexander von Humboldt's support, published between 1851 and 1864 some forty studies on Arabic mathematics. He was Franz Woepcke (1826-1864), who unfortunately died too young at the age of 38. His works written in French, some of which remain unsurpassed even today, constitute a solid foundation for the historiography of Arabic-Islamic mathematics of our times. Particularly impressive was his dissertation *L'algèbre d'Omar Alkhayyâmî*, which appeared in 1851. Here Woepcke establishes that the book on algebra by the philosopher, astronomer and mathematician 'Umar al-Haiyam from the second half of the 5th/11th century contains a systematic treatment of cubic equations. This conclusion surprised the contemporary mathematicians all the more because they remembered the sweeping judgment by Jean-Étienne Montucla,[7] who was considered an authority on the history of mathematics, to the effect that the Arabs did not go beyond quadratic equations in algebra. Thus the intensive and extensive research and studies of the great Arabists J.-J. Sédillot, L.-A. Sédillot, J.-T. Reinaud and F. Woepcke opened up remarkable and hitherto unanticipated perspectives for the future research on the role of the Arabic-Islamic scholars in the universal history of science.

The powerful impulses given by these four scholars were not without consequences, when in 1876 Eilhard Wiedemann (1852-1928) began his studies, which he was to continue for half a century. Wiedemann was a physicist and the majority of his publications are in the field of physics and technology, yet, as time passed, he extended his interest to almost all branches of Arabic-Islamic science. The written output of this indefatigable scholar appeared in more than 200 articles and monographs. His works, later collected in five extensive volumes,[8] were of decisive

[7] *Histoire des mathématiques*, vol. 1, Paris 1758, p. 359 f.

[8] The first two volumes, published by Wolfdietrich Fischer under the title *Aufsätze zur arabischen Wissenschaftsgeschichte* (Hildesheim and New York 1970), contain the 81 articles by Wiedemann which appeared in 'Sitzungsberichte der Physikalisch-medizinischen Sozietät zu Erlangen'. The great majority of his other writings were collected in three volumes as *Gesammelte Schriften zur arabisch-islamischen Wissenschaftsgeschichte* by Dorothea Girke and Dieter Bischoff (Frankfurt: Institut für Geschichte der Arabisch-Islamischen Wissenschaften 1984).

influence on the historiography of natural sciences during the author's life-time as also later on, and will be indispensable for future research.

[ix] Moreover, Wiedemann attracted a large number of pupils and entrusted them with research on important aspects. The work produced by them was as substantial as that of the teacher. This has constituted until now, and will continue to be so in future, the building blocks for the historiography of the natural sciences cultivated in the Arabic-Islamic world.

It is a pleasant duty for me to state that in our efforts to construct and reconstruct instruments, devices and tools which were used, developed, or invented in the Arabic-Islamic world, we have once again Eilhard Wiedemann as the forerunner to be emulated. He reports in several of his writings that he and his assistants reconstructed one or the other instrument. Unfortunately, I was not able to find out more about the fate of his models, beyond the fact that in 1911 the Deutsches Museum in Munich bought five pieces from Wiedemann and the mechanic F. Kelber, who worked with him. The correspondence on the astrolabe, which was among them, shows the difficulties that were encountered at that time, especially in reproducing the letters of the alphabet. Upon the request of the Museum to have these engraved in Arabic, Wiedemann replied thus: "I suggest that the numbers on the astrolabe be chiseled in our script. In Arabic script, they would need to be engraved, which would be expensive and would also mean much trouble for me." We know now that the prototype for Wiedemann's model was an astrolabe by Muḥammad Ibn aṣ-Ṣaffār (420/1029, see vol. II, p. 95), which is now in the possession of the Staatsbibliothek at Berlin. The instrument "was manufactured; the doubtful areas on the limb and on the back remained empty; instead of engraving the legends, appropriately printed papers were pasted on the plates and on the rete."[9]

The instruments and apparatuses, tools and devices which are described in the present Catalogue and are depicted in its illustrations were produced for the purpose of contributing — together with the publications of the Institute for the History of Arabic-Islamic Sciences which was founded in 1982 at the Johann Wolfgang Goethe-University at Frankfurt — towards a revision of the prevailing negative notions about the achievements made over around eight hundred years in the Arabic-Islamic world. While striving for such a revision, we proceed neither in our basic assumptions nor in our actions in a heuristic manner, but believe [x] in the unity of the history of science, thus adhering to the credo formulated by Reinaud and Favé to the effect that the common scientific heritage of mankind grows by continuous steps, though not always in a linear fashion but though with varying

[9] Burkhardt Stautz, *Die Astrolabiensammlungen des Deutschen Museums und des Bayerischen Nationalmuseums*, München 1999, pp. 385-386.

speed. When a particular culture area at a given time takes the lead, or rather, is led to take the scientific heritage further by yet another step, be it large or small, then the historical conditions and the level of progress achieved by the forerunner are the factors that influence the speed and the progress, if any, of the successor. The dominant position of the Greeks is generally acknowledged and appreciated by the historiography of science. Yet, there is still some uncertainty about the question, which Greek scholars do not like to discuss, about the directly or indirectly inherited achievements from the previous and neighboring culture areas which the Greeks drew upon and elaborated further. On this, Otto Neugebauer said as late as in 1932: "Every attempt to connect Greek [science] with pre-Greek [science] encounters strong opposition. The possibility of having to modify the received notion about the Greeks is always unwanted, in spite of all the changes which the received notion underwent from Winkelmann's time onwards by the simple fact that since then, to the 2500 years of 'history', another 2500 years more have been added, and the Greeks are therefore in the middle [of history] and not any more at the beginning."[10]

Here one may mention a fact to which, in my view, enough attention has not been paid so far in the history of science; namely that we can recognize the sources and the forerunners of the Arab-Islamic scholars more easily and more clearly than in the case of other cultures known to us. Indeed Arab scholars were in the habit of quoting their sources with precision and of mentioning their forerunners, in particular the Greeks, with high respect and gratitude. Thus they enable us, for example, to trace the otherwise unknown instruments of the Greeks, or to recover from quotations fragments of Greek writings, which have been lost in the original.

[**xi**] It is true that, since the powerful impetus we owe to J.-J. Sédillot, L.-A. Sédillot, F.-T. Reinaud and F. Woepcke, much has been contributed by the Arabists, who were interested in the history of science, towards modification of the prevalent unfounded notion about the achievements made by the Arabic-Islamic world in

[10] *Zur geometrischen Algebra*, in: Quellen und Studien zur Geschichte der Mathematik, Astronomie und Physik (Berlin) 3/1936/245-259, esp. p. 259. In his innumerable publications, Neugebauer strove to clarify the question about the forerunners to the Greeks in the areas of astronomy and mathematics; see, besides his monumental work *A History of Ancient Mathematical Astronomy* (3 vols., Berlin, Heidelberg, New York 1975), the following publications: *Über griechische Mathematik und ihr Verhältnis zur vorgriechischen*, in: Comptes rendus du Congrès international des mathématiciens (Oslo 1936), Oslo 1937, pp. 157-170; *Über babylonische Mathematik und ihre Stellung zur ägyptischen und griechischen*, in: Atti des XIX Congresso Internazionale degli Orientalisti (Roma 1935), Rome 1938, pp. 64-69; *The Survival of Babylonian Methods in the Exact Sciences of Antiquity and the Middle Ages*, in: Proceedings of the American Philosophical Society 107/1963/528-535; *Babylonische Mathematik und Astronomie und griechische Wissenschaft*, in: 400 Jahre Akademisches Gymnasium Graz. Festschrift, Graz 1973, pp. 108-114.

the intellectual history of humankind. Even so, E. Wiedemann's lament of 1918 unfortunately remains valid: "Again and again we encounter the view that the Arabs have merely preserved for us through translations the knowledge gained from antiquity without, however, adding anything substantially new."[11] The reason is mainly to be seen in the fact that in the historiography of science there prevails a persistent attitude which ignores the approximately 800 year long creative period of the history of science, thereby also already decisively influencing schoolbooks, the basic notions of modern man with regard to the history of science. This judgment holds good not only for the Occident, but in its widest sense also for today's Arabic-Islamic world, where school books are designed according to American or European models.

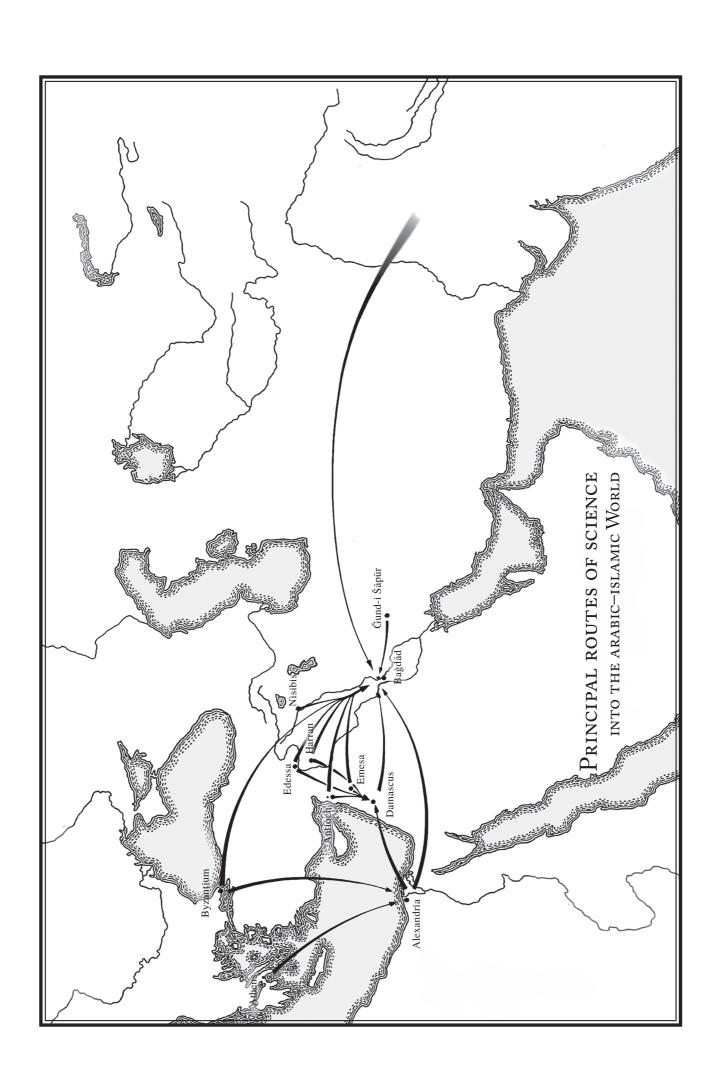
We hope the future visitors can acquaint themselves either in the Museum here or in exhibitions elsewhere with the instruments and devices of our Museum, which are described in the present Catalogue; we hope that this acquaintance will contribute to the concept of the unity of the history of science, which states that in the period between late antiquity and the European modern age the Arabic-Islamic world was the one most capable of development and the most influential cultural area and was the essential link between the Old World and the emerging Occident.

The introduction in the present first volume of the Catalogue is also to serve as an aid to the hoped-for revision. At first, the introduction was planned as a simple outline in order to provide the user of the Catalogue with some historically helpful information. During the course of writing, it took on the present form because the material to be communicated to the reader was much more than at first envisioned. The presentation appearing under the audacious title *Introduction to the History of Arabic-Islamic Sciences* is an attempt, perhaps the first of its kind, to summarize briefly and in chronological order the relevant conclusions arrived at in research to date, without introducing — just for their sake — the eminent personalities who were responsible for the development. It is an attempt, which may have its validity for some time [**xii**] and, considering the research into Arabic-Islamic natural sciences which is fortunately progressing well today, it may soon hopefully serve as a spring board for an enlargement of this presentation.

In the case of a small portion of our astronomical and medical models, we have depended upon the exhibits in museums without, of course, being able to achieve the perfection of the originals. The largest part of our models are based on illustra-

[11] *Die Naturwissenschaften bei den orientalischen Völkern*, in: Erlanger Aufsätze aus ernster Zeit, Erlangen 1917, pp. 49-58, esp. p. 50 (reprint in: E. Wiedemann, Gesammelte Schriften, vol. 2, pp. 853-862, esp. p. 854).

tions and descriptions in Arabic, Persian, Turkish or Latin sources, either on the basis of the originals or of studies. A certain number of models were produced in our workshop. In the reconstruction of the larger part, we depended on the help of people from outside. In this connection, my sincere thanks are due to Günter Hausen (Frankfurt, Institut für angewandte Physik), Herbert Hassenflug (Frankfurt, Physikalisches Institut), Matthias Heidel (Frankfurt), Werner Freudemann (Frankfurt), Gunnar Gade (Marburg), Professor André Wegener Sleeswyk (Groningen), Dr. Günther Oestmann (Bremen), Dr. Felix Lühning (Bremen), Mahmut Inci (Düsseldorf), Martin Brunold (Abtwil, Schweiz), Eduard Farré (Barcelona), Aiman Muhammad ʿAlī (Cairo), ʿAbdalwahhāb Kāẓim (Cairo), ʿAlī Wafāʾ (Cairo) and Kurultay Selvi (Istanbul).

For the preparation of the Catalogue, I owe thanks, besides to my colleague Eckhard Neubauer, to Mr Danièl Franke who designed the layout, prepared the photos and drawings, independently worked on the chapter on "Antique Objects" (Ch. 13) and who, with his knowledge and critical interest, substantially contributed to the success of the undertaking, as also to my colleague Mr. Lutz Kotthoff, who fabricated many of the models in our workshop, made an inventory of the artifacts and contributed technical drawings as well as descriptions of the instruments. I thank my colleagues Dr. Gesine Yildiz, Dr. Carl Ehrig-Eggert and Norbert Löchter for compiling the indices and bibliographies. Dr. Annette Hagedorn (Berlin) very kindly took up the description of glass and ceramics with oriental designs (Ch. 14). My thanks are also due to UNESCO for the financial support for printing the French version of the Catalogue.

I cannot thank my wife adequately enough, not only for following the various stages of the preparation of the manuscript of the Catalogue and for repeatedly reading the proofs, but above all, for being at my side through all the difficulties while setting up the museum and for giving me encouragement.

Frankfurt, August 2003 Fuat Sezgin

SUMMARY

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Byzantium
Athens
Edessa
Nisibis
Harran
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Emesa
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Baġdād
Alexandria

Principal routes of science into the arabic–islamic World

I.
THE DEVELOPMENT OF SCIENCE IN ISLAM
From the 1st/7th to the 10th/16th Century

I have done what everybody should do in their profession accept the achievements of your predecessors gratefull do not shrink from correcting possible blunders and bequeath what seems worthy, to your successors and future generations. al-Bīrūnī (d. 440/1048)

[1] IN AN INTRODUCTION to the present Catalogue it is a difficult task to convey to the reader an adequate idea of the importance of the Arab-Islamic culture area in the universal history of science. It is difficult, not only because only a modest part of the extant source material of manuscripts in Arabic, Persian and Turkish has been published and only a small portion analysed so far. There are various other reasons that render such an undertaking difficult. The reception and assimilation of Arab-Islamic science, right in the middle of its active phase, encountered hostility and violent rejection in the Occident as early as in the second half of the 7th/13th century. This hostile current, motivated to a large extent by religious zeal and sustained up to the 19th century in spite of some resistance, has deeply influenced the spirit and mode of presentation in the historiography of science in Europe since the 16th century. Influenced by this current, historians of science were led, noticeably for the first time in the 18th century, to a view of universal history, wherein the expression Renaissance automatically, by definition, resulted in the denial of any creative status for Arab-Islamic sciences in the intellectual history of mankind. In a crude periodisation of the history of science that is far removed from reality, the phenomenon called Renaissance[1] is conceived as an immediate continuation of the Greek period. In this chronological vault Arab-Islamic culture remains at best in the role of a transmitter through preservation and translation of certain Greek texts.

While the battle against the reception and assimilation of Arab-Islamic science, which had already begun in the 13th century, continued for a long time with full vigour, Arabist research emerged in some European countries in the 18th century directed towards understanding Islam together with its related cultural and intellectual wealth through the study of the sources. This discipline known as Arabic studies which, by nature, does not always display ideal traits and [2] lacks, not infrequently, objectivity in the interpretation and appraisal

[1] In his book *Héloïse et Abélard* (Paris 1938), the French philosopher Étienne Gilson speaks of a "professors' Renaissance" (English translation, 1951, p. 128) and states: "The interpretation of the Renaissance and of the Middle Ages, which we now happen to be reading is not at all, as we would like to think, an historical hypothesis warranred by the facts. It is one of those fundamental positions which G. Séailles might have willingly gathered into his *Affirmations de la conscience contemporaine*. There is no discussing such an affirmation. It is not dictated by facts. It proceeds from the conscience; and it is the conscience that dictates the facts."

"… A real fact, once eliminated, gives place to a feigned fact, created. Then one comments upon it, takes his stand upon it in order to eliminate from history all facts to which this phantom cannot be accomodated." (ibid, p. 132). Cf. H. Schipperges, *Ideologie und Historiographie des Arabismus,* in: Sudhoff's Archiv, Beihefte, Heft 1, Wiesbaden 1961, p. 14.

of the subject of its study, has, nevertheless, achieved much in the course of its two centuries of history through numerous studies, editions and translations of sources, through the preparation of reference books as well as the collection and cataloguing of Arabic, Persian and Turkish manuscripts in European libraries. Although it was not able until now to challenge the prevailing depiction of the so-called "Renaissance" in history books, certain traces of revision are, however, visible thanks to the efforts of scholars like Jean-Jaques Sédillot (1777-1832) and his son Louis-Amélie (1808-1875), Joseph-Toussaint Reinaud (1795-1867), Franz Woepcke (1826-1864) or Eilhard Wiedemann (1852-1928). To date George Sarton (1884-1956) has been the only historian of science who has made the effort to fully utilize the results of Arabist research. This he did in a masterly way in his *Introduction to the History of Science.*[2] Unfortunately the conclusions he drew seem to have received too little attention in the historiographic works written subsequently on individual branches of the natural sciences. It is also regrettable that school books do not display any revision worth mentioning in the attitude inherited from the prevailing historiography of science. My generation grew up in a period when this attitude could assert itself with unshakable firmness in school books. A true revision can only be expected from future research conducted on a broad basis. However, the decisive factor in this process will be that the results of research become accessible to a wider circle of interested persons. An effective means of communication would be to make known the tools and instruments which were used, developed or invented within the framework of Arab-Islamic science and technology, and to reconstruct them if they are no longer available. Such communication is the goal of the present Catalogue and of the Museum the exhibits of which are described here.

[2] Published in 5 volumes, Baltimore 1927-1948.

After these introductory remarks, I move on to present an overview of the position of Arab-Islamic science in the context of the universal history of science.

The 1st/7th Century

As early as in the third decade after the advent of Islam, the state that was brought into existence by it extended its borders through conquests; in the north up to Asia Minor and western Persia and in the south-west down to Egypt. Through the capture of Damascus in the year 15/636, of Emessa (now Ḥimṣ) and Aleppo in the year 16/637, of Antioch (now Antakya) in the year 17/638 and of Alexandria in the year 21/642, the Muslims came into lasting contact with the inhabitants of these cities who had belonged to what was formerly the Roman and later the Byzantine empire. It is well known that the conquerors treated the inhabitants of these traditional centres of learning well and knew how to profit from their knowledge and technical skills. Without such a policy it would be inconceivable that the Muslims [3] could have been able to seize the island of Cyprus as early as in the year 28/649 with an armada, pillaged on the coastline of Sicily in the year 31/652 and seized Rhodes shortly thereafter.[3]

Indeed, especially favourable circumstances existed for a gradual transition from conquerors to appropriators of the cultural wealth of their converted and non-converted fellow citizens, in particular, from the commencement of the Umayyad rule in 41/661. A surviving Arabic manuscript on alchemy claims to be a translation of a work by the Greek alchemist Zosimos (350-420) supposedly made as early as in 38/658.[4] If we give credence to this statement, it would mean that the interest in translating Greek texts was already awakened in the

[3] v. F. Sezgin, *Geschichte des arabischen Schrifttums,* vol. II, p. 6.

[4] ibid, vol. 4, p. 75.

governorship of Muʿāwiya I, who subsequently became the first Umayyad Caliph.

In the context of the history of mathematics, Julius Ruska explained in 1917 quite rightly the early willingness and the ability of the Arabs to absorb foreign cultural wealth: "It cannot be reiterated often and emphatically enough that the Arabs who flooded the Persian and Roman provinces brought with them neither ready-made jurisprudence nor state administration but were obliged to take over the administrative methods and legal procedures of the conquered regions without any basic change. That they succeeded, with amazing speed, in adapting themselves to the circumstances at large and in incorporating not only the state apparatus but also other fruits of an ancient, mature civilization is well known. This would indeed have been impossible had the intellectual distance between the conquering people and the contemporary Persians, Greeks and Egyptians been as great as it has been generally assumed until recent times. In particular, we should not treat the city-dwelling Arabs, who were the bearers of the intellectual and political movements, as semi-savages who had been, before Muhammad's appearance, unreceptive to any cultural influences from the neighbouring peoples or that they were hardly literate in the very period in which they gained importance in the history of mathematics."[5]

The inhabitants of the ancient cultural centres appear to have suffered no great difficulties in the course of their integration into the new society. Christian physicians, for example, were employed at the courts of the early Umayyad rulers. It is reported that one of them, Ibn Aṯāl by name served under Muʿāwiya I (r. 41/661-60/680). Another Christian physician, Abu l-Ḥakam, was also in Muʿāwiya's service. He was entrusted by the ruler with the task of preparing medicines.[6] In many areas of state administration, the Umayyads had to rely on the services and the support of the inhabitants of the conquered regions. Such collaboration seems to have functioned well. For a while local languages were still used in taxation and administrative practice; they were the Coptic language in Egypt, Greek in Syria, and Persian in Iraq and Persia. The use of the Arabic language for official records was introduced only later. In Syria, this happened at the instance of the ruler ʿAbdalmalik b. Marwān in 81/700, in Iraq on the orders of the governor al-Ḥaǧǧāǧ b. Yūsuf in 78/697, in Egypt at the time of the governor ʿAbdalmalik b. Marwān in 87/705 and in north-eastern Persia (Ḫurāsān) under Caliph Hišām b. ʿAbdalmalik in 124/742.[7]

[4] In the spirit of the already existing interest in the integration of the knowledge available in the cultural centres of the conquered regions, the first medical book was translated into Arabic under the Umayyad Marwān I (r. 64/683-65/685). It was the manual (*Kunnāš*), written in Greek by the Alexandrian presbyter Ahron (flourished probably in the 6th cent. CE), which was first translated into Syriac by one Gōsiōs and then from this version rendered into Arabic by the Jewish physician Māsarǧawaih of Baṣra, who expanded it with two chapters of his own. This translation is said to have been kept in the library of Caliph ʿUmar b. ʿAbdalʿazīz (r. 99/717-101/720), who made it accessible to the general public.[8]

From the first century of Islam and from the turn to the second, the titles of some translations into Arabic have come down to us. Several of these, including alchemical and astrological works, have been translated, as indicated in the manuscripts, upon commission by the Umayyad prince Ḫālid b. Yazīd (d. ca.

[5] J. Ruska, *Zur ältesten arabischen Algebra und Rechenkunst,* Heidelberg 1917, pp. 36-37; F. Sezgin, op. cit., vol. 5, p. 8.

[6] v. F. Sezgin, op. cit., vol. 3, p. 5.

[7] v. Ibn an-Nadīm, *Fihrist,* p. 242; F. Sezgin, op. cit., vol. 5, p. 21.

[8] v. F. Sezgin, op. cit., vol. 3, pp. 5-6, 166-168, 206.

102/720).[9] This prince, with a series of extant tracts and as evidenced by frequent statements in literature, appears to be the first Arab in the history of science who occupied himself with alchemy and wrote on it. Of course, one should not expect from this exercise anything more than a mere adaptation or imitation of texts that became available to him through translations which he himself had commissioned, or through direct contact with his teachers who were the representatives of the cultures of the conquered regions. In this context, Damascus and Alexandria are mentioned as centres of activity. Among the translations of astrological works sponsored by Ḫālid b. Yazīd there was the "Book of the Fruit" (καρπός; *Kitāb aṯ-Ṯamara*) by Pseudo-Ptolemy; this translation was still available to al-Bīrūnī in the first half of the 5th/11th century.[10] Apparently Ḫālid b. Yazīd occupied himself with astrology as well. The famous astrologer Abū Maʿšar[11] (171/787-272/886) counts a book by Ḫālid among the well-known astrological works.[12] Based on the translation of the medical manual by Ahron and the translations commissioned by Ḫālid b. Yazīd as well as his own activity as an author, we may assign, *cum grano salis*, the commencement of the period of reception of foreign scientific traditions in the Arab-Islamic culture area to the last third of the first century of Islam. Naturally, the wealth of foreign knowledge appropriated by the Arabs at that time was not only of Greek origin. We learn, for example, that a geographical work in Persian which had been in the possession of the Sassanid princess Šāhāfirīḏ fell into the hands of the conquerors after her capture during the conquest of Ḫurāsān by Qutaiba b. Muslim (d. 96/715).[13]

Similar occurrences are reported by the great Islamic thinker al-Bīrūnī (d. 440/1048). In his fundamental work on mathematical geography, *Taḥdīd nihāyāt al-amākin,*[14] he mentions the fact that he saw in Ġazna, in modern Afghanistan, a book of astronomical tables (*Zīǧ*) written on old parchment with dates according to the Diocletian Era, and that in an appendix there were additions by a scholar with records and dates of solar eclipses that had been observed between 90 and 100 Hiǧra. He found in it, adds al-Bīrūnī, also references to the latitude of the city of Bust and to the obliquity of the ecliptic.[15]

[5] Of great importance for the early period of the reception was certainly the translation of the alleged epistles of Aristotle to Alexander the Great, including the book περὶ κόσμου under the Umayyad Hišām b. ʿAbdalmalik (r. 105/724-125/743). With the translation of this pseudo-text, which dates presumably from the second half of the 2nd century CE, the Arab-Islamic culture area received a limited knowledge of geography which however went beyond the borders of the Islamic territory, of meteorology differing from the native conception of atmospheric phenomena as well as the fundamental Greek conception of the Earth: the Earth is situated at the centre of the universe. The latter moves unceasingly, together with the entire heavens. The fixed stars revolve together with the heavens. The number of stars is unfathomable for human beings. The planets are seven in number. They differ from one another in their nature and speed as also in their distance from the Earth, and move on their own individual orbits which lie one inside the other and are enclosed by the sphere of the fixed stars.[16]

[9] v. F. Sezgin, op. cit., vol. 4, pp. 56, 82-83, 89; vol. 7, p. 9.
[10] v. ibid, vol. 7, p. 42.
[11] v. ibid, vol. 7, pp. 139-151.
[12] v. ibid, vol. 7, p. 15.
[13] v. ibid, vol. 10, p. 64.
[14] Ed. Cairo 1963, p. 268.
[15] v. F. Sezgin, op. cit., vol. 6, p. 122.
[16] v. F. Sezgin, op. cit., vol. 6, p. 72; *Risālat Arisṭāṭālīs ila l-Iskandar fi l-ʿālam,* MS Tehran, Dānišgāh 5469 (fol. 36b-41b); H. Strohm, *Aristoteles. Meteorologie. Über die Welt,* Berlin 1970, pp. 240-241.

Without wishing to amass further examples which, in any case, survive only in fragments and rather sparsely, we may draw attention here to an important feature of this early phase of reception which is characteristic of the entire period of reception and the assimilation of sciences in the Arab-Islamic culture area. The process of integrating foreign knowledge took place quite openly from the beginning, without any reservations and without any hidden motive which, as we shall see, was regrettably not the case with regard to the subsequent reception and assimilation of the Arab-Islamic sciences in Europe.

In 1965 Franz Rosenthal explained the motivation for the urge to acquire foreign knowledge in the following words:[17] "Neither practical utilitarianism, however, which made an acquaintance with medicine, alchemy and the exact sciences appear desirable to Muslims, nor theoretical utilitarianism which prompted them to occupy themselves with philosophical-theological problems, might have sufficed to support an extensive translation activity, had not the religion of Muḥammad stressed from the very beginning the role of knowledge (*'ilm*) as the driving force in religion and, thereby, in all human life … Without this central position of 'knowledge' in Islam and the almost religious veneration extended to it, the translation activity would presumably have been less scientific, less scholarly and less extensive. It would probably have been confined to the absolutely essential and immediately useful to a much greater degree."

The progress in the field of science achieved quite early in the young Islamic society of the first century with regard to the wealth of knowledge of foreign provenance, took not only place through the translation of books, of course. The circumstances arising out of the new religion, which were certainly not so primitive as is often assumed, quickly induced the Arabs to engage themselves with new intellectual challenges; in particular, there arose an astounding urge towards the art of writing. Going through the relevant sources, one is given the impression that towards the end of the 1st/7th century the level of literacy of the people in the Islamic territory reached a degree that had no comparison in the contemporary Middle Ages. The variants found in [6] the copies of the Quran circulating immediately after the Prophet's death urged the Muslims to prepare a universally acceptable version of the Quran. That was a philological task. The interpretation of many uncommon words in the Quran led not only to the emergence of the first commentaries on the Quran but also awakened the interest in lexicography. Likewise, quite early on, a significant philological tool was established in the use of poetic material as linguistic evidence. This recognition resulted in an appropriate appreciation of the poems of the pre-Islamic period and of the period of transition to Islam, and led to the activity of collecting and preserving the poetic material available in book form or in fragments. Over the course of centuries, the philological achievements which commenced with the simple interpretation of the Quranic vocabulary developed to such a height that–with regard to the inner principles as also to the outer extent–they "could be compared only with those of the Chinese."[18]

The Arabic sources assign the beginnings of Arabic grammar also to the 1st/7th century. Only with such an early start can the enormous development of the 2nd/8th century be understood.

The intense activity of collection and preservation in writing of the sayings of the Prophet (*ḥadīṯ*) led to a special manner of transmission, the principles and rules of which have often been misunderstood by modern scholars.

[17] v. F. Rosenthal, *The Classical Heritage in Islam, London* 1975 (translated from the German: *Das Fortleben des Antike im Islam*, Zurich 1965), p. 5.

[18] v. F. Sezgin, op. cit., vol. 8, p. 15.

The quest of recording in writing the Prophet's biography and his conquering expeditions as well as the biographies of his successors paved the way to the development of a variegated historiography of enormous proportions, including the separate treatment of the history of science that emerged quite early on as well. To my knowledge the issue of the significance of this historiography, which arose in a purely Islamic intellectual milieu, and of the methodology developed within it has not at all or at least not adequately been treated as yet in the context of the universal history of the subject. Even Arabists underestimate the historical content of the majority of the historical writings that arose primarily in the first three centuries of Islam (7th-9th cent. CE) because of the peculiar method of quoting their sources. The individual historical reports (*ḫabar*, pl. *aḫbār*) in those works which are, in most cases, preceded by a chain of transmitters as evidence of their authenticity, and which can, in some cases, be accompanied by the respective authors' own remarks or comments, are unfortunately considered, either as reports that were handed down orally for centuries, or as personal views of a particular transmitter written down according to certain tendencies one or two generations before the book in question was composed. Without going into further details in this introduction, it may be stated that those chains of transmitters contain the names of the authors of written sources as well as their transmitters, who were authorized, according to strict rules, to hand down certain named sources.[19] In modern terms, the chains of transmitters appearing in Arabic works on history can be considered as references to the sources, somewhat like those given in the footnotes of our books.

The earliest written sources of juridical themes are likewise to be sought in the 1st/7th century and as early as in the first half. Naturally in these early records of modest extent only individual themes are treated. More extensive compendia of Islamic law, with a systematic approach to the matter, [7] began to appear in the first half of the 2nd/8th century.[20]

The process of reception of foreign knowledge and culture developed rapidly in the first half of the 2nd/8th century qualitatively as well as quantitatively and extended to almost all areas of knowledge of that time. The sources used comprised not only Greek works in direct translation or mediated by a Syriac translation, but also Middle Persian texts.

An important feature of the early translations from the Greek consisted in the fact that they were pseudo-epigraphs; thus they bore the names of well known authorities from Antiquity like Aristotle, Socrates or Ptolemy as ostensible authors. These arose in the tradition of the pseudo-epigraphic Greek literature which can be traced back at least to the 2nd century BCE. The content of the pseudo-epigraphs preserved in Arabic translation creates the impression that most of them were produced in late antiquity, shortly before the rise of Islam. They show the state of experience and the developments of the period of their origin and appear to emanate mainly from the eastern regions adjoining the Mediterranean Sea. The reason why very few of these pseudo-epigraphs translated into Arabic are extant in the Greek original in full or in part lies, in my view, in the fact that the majority of them were produced just before the advent of Islam in such cultural centres that were to become part of the Islamic territory as early as in the first half of the 1st/7th century. Once they were translated, further preservation of the Greek originals was left to chance. Naturally neither the translators nor the readers knew or were in a position to know that the writings bear the names of fictitious authors. Arab-Islamic scholars quoted these titles as true writings of their alleged authors, even after the original writings of those

[19] v. F. Sezgin, op. cit., vol. 1, pp. 236-256.

[20] ibid, vol. 1, pp. 393 ff..

authors became available in Greek and in Arabic translation. They became acquainted with, for example, the pseudo-writings of Aristotle, Plato or Ptolemy, before they knew their real works, and used one or the other side by side as of equal merit. Many of these books were translated subsequently as the work of their pseudo-authors, from the Arabic into Hebrew and Latin and were then regarded as authentic for centuries in the Occident as well.

In my *Geschichte des arabischen Schrifttums,* I have discussed on several occasions the question of the period of origin and the significance of these pseudographs attributed to Greek, Babylonian, Persian or other authors and preserved in Arabic writings in part or in full. While referring to my discussion therein,[21] I limit myself here to the remark that most Arabists consider these not as translations but as forgeries by Arab-Islamic scholars. This would mean that these scholars first composed the pseudo-writings themselves in order to cite them subsequently as real, as is the case particularly in the earliest Arabic texts. In this scenario the question remains open whether the Arabs and early Muslims, given their geographical and cultural-historical circumstances, were in the position at all of inventing the contents of those writings which were, in part, very extensive. Through the late dating and the devaluation of these pre-Islamic pseudographs preserved in the body of Arabic literature, important material for the history of science of late antiquity is, unfortunately, lost.

[8] The 2nd/8th Century

The range of reception from the adjacent civilizations was substantially increased in the second half of 2nd/8th century. Receptivity also developed steadily and quickly thanks to many favourable circumstances. As regards the process of reception, one should not, of course, think merely of books and their influence. In the role played for some time by the representatives of the cultural centres of the conquered lands of the Eastern Mediterranean area as teachers of the Muslims, the position of the conveyors of knowledge and culture of the vanquished Persian-speaking area is particularly remarkable.

We are quite well informed about the reception of foreign knowledge under the Sassanids, particularly under Šāpūr I (r. 242-272).[22] The scientific knowledge borrowed mainly from the Greeks and Indians, and probably also indirectly from the later Babylonians, received some impetus here. In connection with the area of knowledge cultivated in the Sassanid Empire in a rather syncretistic manner, we can notice an accelerated process of reception on the part of the Arabs in the fields of astronomy, astrology, mathematics, geography, philosophy and medicine.[23] We may cite here three events from astronomy, philosophy and medicine illustrating this development.

The revision of the astronomical tables in the *Canon* of Ptolemy with the help of Indian tables resulted in certain corrections. The youngest redaction of this revision, commissioned by Yazdağird III (r. 632-651), was translated into Arabic under the title *Zīğ aš-šahriyār* probably in the first half of the 2nd/8th century. It seems to have had quite a stimulating effect on Arab-Islamic scholars so that they occupied themselves with scientific astronomy at an early stage.[24]

In the field of philosophy, some parts of the Aristotelean *Organon* in Middle Persian translations were rendered into Arabic by ʿAbdallāh Ibn al-Muqaffaʿ[25] (d. 139/756). Ibn al-Muqaffaʿ

[21] v. F. Sezgin, op. cit., vol. 4, p.15 ff., 31 ff.

[22] v. ibid, vol. 6, p. 106 ff.

[23] v. ibid, vol. 3, pp. 182-186; vol. 4, pp. 59-60; vol. 5, p. 205 ff.; vol. 6, pp. 106-111; vol. 7, pp. 69-71, 80-88.

[24] v. ibid, vol. 5, pp. 203-204; vol. 6, pp. 107-110, 115.

[25] v. ibid, vol. 7, p. 322; in greater detail in the manuscript of the chapter on light and popular literature, of the *Geschichte des arabischen Schrifttums,* which was prepared some 20 years ago.

was of Persian descent and one of the most eminent writers of his time. He influenced the course of the reception through translations of Persian books from various branches of knowledge, besides through his own works. Among others, there was his translation of the *Kalīla wa-Dimna,* a mirror of princes in the form of animal fables which is said to have been translated previously from Sanskrit by the Persian Burzōe under Ḫusrau I Anūširwān (r. 531-579). The introduction added by Burzōe contains one of the oldest extant discourses concerning medical ethics and is, at the same time, the autobiography of a physician.[26]

As to the reception of medicine in a narrower sense in the first half of the 2nd/8th century, we may mention that the famous Sassanid centre of knowledge, Ǧundišāpūr, was intact at least until the time of Caliph al-Ma'mūn (r. 198/813-218/833) and that the physicians from this place were also in touch with Baghdad. It is reported that Ǧūrǧis b. Ǧibrīl b. Buḫtīšūʿ, a chief physician in the hospital of Ǧundišāpūr and author of medical works, was called at an advanced age, in the year 148/765, to Baghdad by Caliph al-Manṣūr to cure his stomach ailment. Moreover, he is said to have [9] translated several medical books from the Greek into Arabic. For his own works he used the Syriac language.[27]

The progress that can be seen in the humanities of the Arab-Islamic culture area in the first half of the 2nd/8th century was immense. Writings on the sciences of tradition (*ḥadīṯ*) and jurisprudence, which hitherto had been limited to single topics, developed into voluminous manuals, divided into subjects. Moreover, the methodology of the science of tradition became more refined. Historiography also gained in breadth and content. In books on the history of conquests, the geographical descriptions of the countries concerned were given adequate space.

The development of the above-mentioned branches of philology was remarkably lively in the first half of the 2nd/8th century. This is true of the collection and codification of Old Arabic poetry and also of the extension of the scope of the material discussed in the fields of grammar and of the development of lexicography. If we take, for instance, the achievements of a man like al-Ḫalīl b. Aḥmad, his important role in the development of lexicography and grammar and in the formation of theory on poetic metres and music is stressed. He was possibly the first to write a comprehensive work on the basis of numerous monographs by his predecessors. Certainly, his *Kitāb al-ʿAin* was assigned the importance of a canonical work of lexicography quite early on.[28]

While the process of reception continued in all intensity in the second half of the 2nd/8th century and also still in the following century, the period of assimilation began at the same time. Important in this connection is the fact that Caliph al-Manṣūr (r. 136/754-158/775) commissioned the translation of the voluminous astronomical *Siddhānta* from Sanskrit into Arabic. The commission was executed by one of the youngest representatives of Sassanid astronomy in Islam, al-Fazārī, in the year 154/770.[29] It is remarkable for those times that there existed not only adequate pre-requisites–including the necessary Arabic terminology for translating the astronomical-mathematical topics–but also the fact that al-Fazārī and his contemporary Yaʿqūb b. Ṭāriq were already capable of discussing, in several treatises of their own, topics of both theoretical and also applied astronomy. They wrote, inter alia, about the use of the planispheric astrolabe and the armillary sphere.[30] I consider this to be the

[26] v. ibid, vol. 3, pp. 182-183.

[27] v. Ibn Abī Uṣaibiʿa, *ʿUyūn al-anbā'*, vol. 1, pp. 123-125; F. Sezgin, op. cit., vol. 3, p. 209.

[28] v. F. Sezgin, op. cit., vol. 8, pp. 51-56

[29] v. ibid, vol. 6, p. 122.

[30] v. F. Sezgin, op. cit., vol. 6, pp. 122-127.

beginning of the phase of assimilation in the field of astronomy.

The desire of the statesman and scientist Yaḥyā b. Ḫālid al-Barmakī (b. 120/738; d. 190/805) to have Ptolemy's *Almagest* translated into Arabic should also be understood in that sense. His desire was fulfilled apparently twenty-five years after the translation of the Indian *Siddhānta*. To judge how high a standard of astronomical learning and science in general had been achieved in the Arab-Islamic culture area by this time, it is revealing to note that the patron was not satisfied with this first translation and commissioned a fresh translation from other scholars.[31]

An even more distinct sign for the beginning of the period of assimilation can be observed in the field of chemistry–alchemy. Several scholars writing in Arabic composed books in [10] this field during the second half of the 2nd/8th century, mostly by following in the wake of the authors of books already translated. One can, of course, consider this to be an assimilation of a modest scale. However, this is not what we have in mind here, but rather the phenomenal appearance of a scholar by the name of Ǧābir b. Ḥaiyān, who in the same period developed from chemist and alchemist to natural philosopher and occupied himself with almost all the areas of knowledge of his time. As we shall show in greater detail in the relevant chapter, his extant treatises numbering several hundred demonstrate that he built primarily upon the knowledge that became accessible in the pseudographs. His writings, the chronological sequence of which can be established with the help of the numerous cross-references in his own works, reveal an extraordinary scientific career. In the field of chemistry–alchemy he appears as a scientist intent on establishing a discipline dedicated to the qualitative analysis of substances found in nature by determining their quantitative proportions. According to him, all elements of human knowledge can be traced back to a system of quantity and measurement that leads to a principle of equilibrium which he calls the "law of measurements" (*ʿilm al-mīzān*). At the beginning of his career, Ǧābir appeared as one of the protagonists in the process of assimilation but soon developed into a bold and highly creative natural philosopher (infra vol. IV, 99ff.).

The simultaneous progress in the field of the humanities also proceeded at an amazing pace. Each scholar built upon the works of his predecessors, extended them as well as he could and thus rendered those works, to some extent, dispensable. An example of this is the book of grammar, "The Book" (*al-Kitāb*) by ʿAmr b. ʿUṯmān Sībawaih[32] (d. probably 180/796). This monumental work, considered by later generations as the canon of grammar, through its size and systematic structure bears evidence of the fast and substantial development of the sciences in Arab-Islamic culture within a short span of time.

The 3rd/9th Century

In the first two decades of the 3rd/9th century, the process of development of the sciences assumes a completely new character which can be considered the beginning of the period of creativity. While the sciences cultivated in the Islamic world were still able to profit in their constant qualitative and quantitative development from the favourable conditions of the preceding century so that they could continue their way into the 3rd/9th century at an undisturbed pace, they received in its first decades additional, entirely new impulses through Caliph al-Maʾmūn (r. 198/813-218/833). As an admirer of Greek science, this ruler had Greek books from Byzantium and from the conquered cultural centres brought to Baghdad and commissioned translations into Arabic not only of works that had not previously been translated,

[31] v. F. Sezgin, op. cit., vol. 6, p. 85.

[32] v. ibid, vol. 9, pp. 51-63.

but saw to it that many of the older translations were revised.

According to our not yet very detailed knowledge, al-Ma'mūn seems to have facilitated and organized the work of his scholars through an institution named "House of Wisdom" (*Bait al-ḥikma*). The Caliph himself was knowledgeable in various branches of science. Several important works were produced upon his incentive and oftentimes he was personally involved in the projects. Some of his achievements may be mentioned here, in so far as they show a creative character in the sense that he was not content with a result but wanted to go beyond it.

Thus he had the astronomical data in the πρόχειροι κανόνες by Ptolemy (which had been [11] introduced at the time of the first translation of the *Almagest* into Arabic) verified and corrected by his astronomers. The results of this enterprise were published under the title *az-Zīǧ al-mumtaḥan*.[33]

One of the tasks that the Caliph performed together with his astronomers was the calculation of the longitudinal difference between Baghdad and Mecca in order to determine the direction of prayer (*qibla*) as precisely as possible. Here it must be noted that the Caliph did not want to rely on the coordinates of the two cities already known from various tables, but attempted to determine the longitudinal difference from his own observations at the time of a lunar eclipse. The longitudinal difference of 3° thus calculated (actually 4°37') was reasonably accurate.[34]

For the future attempts to determine the surface area of the Earth mathematically, it was of fundamental importance that on al-Ma'mūn's order the task of an accurate measurement of the length of one degree of the meridian was accomplished. A group of his astronomers, using instruments for determining the position of the sun as well as for the precise direction of the meridian and with the help of ropes and sticks, took repeated measurements in the plains of Syria and Iraq and arrived at a value for the length of one degree on the meridian of between 56 1/3 and 57 Arabic miles, establishing 56 2/3 as a mean. This result differs only slightly from the modern value. In Carlo A. Nallino's view, this was–compared with the determination by Eratosthenes which was based on several uncertain assumptions–the first strictly scientific measurement of the Earth, being the result of a time-consuming, strenuous task.[35] Furthermore, the Caliph used the opportunity of his expedition against Byzantium to have the length of a degree of the meridian once more determined by trigonometric means. From a point on the sea shore which was high above sea level, he let the astronomer Sind b. ʿAlī, who accompanied him, measure the depression of the sun at sunset in order to calculate trigonometrically the length of the Earth's radius. This is the very procedure that was later associated with the names of Francesco Maurolico (1558), Sylvius Belli (1565) and Francesco Giuntini (d. 1580).[36]

Caliph al-Ma'mūn's strong interest in astronomy and its development led him to build an astronomical observatory first in the Šammāsīya quarter in Baghdad and thereafter another one on the Qāsiyūn, the local mountain of Damascus. By the use of large instruments and continuous observations he endeavoured to obtain measurements more precise than those of his predecessors. Apparently he was the first in the history of astronomy to establish astronomical observatories in the strict sense of the word.

Finally, we shall mention that project initiated by al-Ma'mūn which can be considered, without any doubt, the most significant and the most consequential for posterity. This

[33] v. F. Sezgin, op. cit., vol. 6, pp. 136-137.
[34] v. ibid, vol. 10, p. 94.
[35] v. ibid, vol. 10, p. 95.
[36] v. ibid, vol. 10, p. 96.

project belongs to the fields of geography and cartography.

After attaining not inconsiderable familiarity with longitudes and latitudes, maps and the geography of countries,[37] scholars in the Arab-Islamic culture area translated Ptolemy's γεωγραφικὴ ὑφήγησις into Arabic. In addition to this at the beginning of the 3rd/9th century Arab-Islamic scholars became acquainted with the geography and maps of Marinus (1st half of the 2nd century CE).[38] In this connection, al-Maʾmūn decided to commission a geographical work with a world map and regional maps, and entrusted this task to a group of scholars. [12] It goes without saying that the latter relied primarily on Ptolemy's Geography which, for its part, was more of a cartography manual than a book on geography. It contained the coordinates of approximately 8000 localities which, with very few exceptions, were not data obtained by astronomical measurement. The coordinates were gathered mostly from the Geography and the maps of Marinus and elaborated further.

The world map discovered about twenty years ago and the surviving regional maps of al-Maʾmūn's geographers together with contemporary tables of coordinates based on these maps open up an entirely new horizon for the history of cartography. Required is, however, the willingness of historians to approach this material without any bias. I have presented my own appraisal in the study *Mathematische Geographie und Kartographie im Islam und ihr Fortleben im Abendland*[39] (constituting volumes 10 and 11 of my *Geschichte des arabischen Schrifttums*) which appeared in 2000, and shall present some crucial points thereof in the cartographic section of the present Catalogue. In this general overview of the position of the Arab-Islamic culture in the universal history of science, I should like to state, instead, the fundamental convictions I have reached during the many years of my occupation with this topic. As great as the efforts of the astronomers and geographers working for al-Maʾmūn may have been, their achievements naturally remained within narrow confines. This had been the case with their Greek predecessors and it was to be true for their successors in the Occident. We must not indulge any more in the naïve and forced attitudes of the history of cartography, such as the notion that at the beginning of the 14th century a priest like Giovanni Carignano[40] should have been in the position to produce at his abode in Genoa, just on the basis of enquiries, a world map with an almost correct depiction of the Mediterranean Sea, the Black Sea, the Caspian Sea and Anatolia, without knowing or using as models the maps made on location by generations of people living there. Or the assumption, to give another example, that in the year 1724 Guillaume Delisle could have, at his studio in Paris, succeeded in drawing the first almost perfect map of Persia with Eastern Anatolia and the Caucasus with hundreds of localities and their coordinates, with the configurations of oceans and lakes, with the outlines of countries and the courses of rivers, without having translated into his mother tongue as a model a native map on which generations had worked.[41]

On the basis of this reality and supported by historical facts, we see that the Maʾmūn geographers substantially improved the cartographic depictions inherited from their predecessors. Their progress can be measured against a world map reconstructed according to the data of Ptolemaic geography by the Byzantine scholar Maximus Planudes around 1300 CE The scholars working for al-Maʾmūn had the advantage

[37] v. F. Sezgin, op. cit., vol. 10, p. 73 ff..

[38] v. ibid, vol. 10, p. 30-32, 80, 82.

[39] English translation: *Mathematical Geography and Cartography in Islam and their Continuation in the Occident*, 2 vols., Frankfurt, Institute for the History of Arabic-Islamic Sciences 2005.

[40] v. ibid, vol. 10, p. 332 ff.

[41] v. ibid, vol. 10, p. 413 ff.

of surveying from Baghdad, which was at that time quite the centre of the inhabited world, South and Central Asia, East and North Africa, relying, as far as possible, on their own observations and measurements. The Maʾmūn map is of epochal importance to us for various reasons. Leaving aside some features of the first vulgata which are not traceable any more, the Maʾmūn map, together with the map reconstructed on the basis of its book of coordinates, reflects the achievements of humankind in the first quarter of the 3rd/9th century regarding the cartographic [13] depiction of the Earth's surface. Thus it provides us with a solid base for the judgement of the further development in which this map itself was of great significance both in the Arab-Islamic culture area as well as in the Occident. Besides its quite elaborate depiction of the Earth's surface, the cartographic techniques used, such as globular projection, cartographic scale and depiction of mountains in perspective, help us to establish a much earlier date for their introduction.

Mathematics, which already had made substantial progress in the second half of the 2nd/8th century, particularly after the introduction of the notion of "zero" with the translation of the Indian *Siddhānta* into Arabic, was enriched in the first two decades of the 3rd/9th century by the almost simultaneous appearance of three works on algebra. Their authors were Muḥammad b. Mūsā al-H̱wārizmī,[42] Sind b. ʿAlī[43] and Abdalḥamīd b. Wāsiʿ Ibn Turk.[44] The works were called the *Kitāb al-Ǧabr wa-l-muqābala*, which means "reconstruction and juxtaposition". These were the first treatments of algebraic linear and quadratic equations, independent of arithmetic. Al-H̱wārizmī states that he wrote his book on commission by Caliph al-Maʾmūn. All three works seem to be based on a syncretistic tradition which had evolved in the Hellenistic Orient, absorbing Greek, Indian and late-Babylonian elements directly or indirectly. The algebra of al-H̱wārizmī and his arithmetic have, after their translation into Latin, deeply influenced mathematics in the Occident since the 12th century.[45]

Towards the end of the first half of the 3rd/9th century, mathematics in Islam seems to have reached the threshold of its period of creativity. Characteristic evidence of this phenomenon can be found in the works of the Banū Mūsā (namely, Muḥammad, Aḥmad and al-Ḥasan, sons of Mūsā b. Šākir). At the time when they were occupied with mathematics, the most eminent works in the field, like those of Euclid, Archimedes, Apollonius, Menelaus and others, were already available. The terminological difficulties had been solved to a large extent. The content of Euclid's *Elements* had been completely assimilated through commentaries written three quarters of a century earlier. With avid interest, older contemporaries of the Banū Mūsā had devoted monographs to the deductive geometry of the Greeks, and through their own monographs the three brothers continued the task thus begun. The works that have come down to us bear witness of their ability to deal with the works of their Greek predecessors in a creative and undaunted manner; how much they really accomplished is not crucial. In their work on geometry they claim to have found a new solution for the trisection of angles. To that end they used a figure which, in a further developed form, became later known as "Pascal's limaçon." The extent of their own accomplishment is less decisive for our judgment than the attitude. The three brothers also undertook mensuration of the circle according to the method developed by Archimedes. They tried hard "to distance themselves as far as possible from their Greek masters by using a different method of proof and by choosing oth-

[42] v. F. Sezgin, op. cit., vol. 5, pp. 228-241.
[43] v. ibid, vol. 5, pp. 242-243.
[44] v. ibid, vol. 5, pp. 241-242.
[45] v. ibid, vol. 5, p. 28.

er letters of the alphabet."[46] They knew Heron's theorem [14] for the area of a triangle, yet they used another proof, influenced perhaps by the geometry of Late Antiquity. Moreover, they were also able to extract the cube root of a non-cube number quite accurately in sexagesimal fractions.[47]

The natural philosopher Yaʿqūb b. Isḥāq al-Kindī (d. shortly after 256/870), a contemporary of the Banū Mūsā, offers interesting clues for the beginning of the period of creativity in the field of meteorology. He deals with[48] all the topics of Aristotelian meteorology following Aristotle and his disciple Theophrastus, but for many problems he provides independent and original explanations, as for instance, on the origin of wind.[49] Being a physicist, he draws on the law of extension: The volume of all bodies shrinks in proportion to the degree of coldness and expands in proportion to the degree of heat. Thus he finds the explanation for the appearance of wind, stating: "Air moves from regions in which heat expands [the air] in the direction of regions where coldness shrinks [it]."[50] At the time when the Sun stands above the northern hemisphere of the Earth, he goes on to say, the air expands because of the heat and streams southwards where it contracts because of the cold prevailing there. He concludes that was why most of the winds in summer blow from the north, but in winter the other way round, unless changes of directions occur owing to topographical conditions and other side effects. This explanation of al-Kindī for the origin of winds and for their direction is almost identical with the modern theory, the precursors of which are purportedly George Hadley (1685-1744) and Immanuel Kant (1724-1804).[51]

It appears that the beginnings of the modern explanation of the causes of ebb tides and flood tides are also to be sought in the first part of the 3rd/9th century. The natural philosopher ʿAmr b. Baḥr al-Ǧāḥiẓ (d. 255/888) transmits the view that low and high tides correspond to the measure of the pull and the push of the moon upon water.[52] This view was formulated more precisely by one of his successors: "the moon behaves towards the sea as the magnet behaves towards iron ore, the former pulling the latter towards itself, in whichever way it turns."[53]

The advances in natural sciences, which we have outlined above on the basis of a few examples, were not inferior to those in the humanities. Yet in the historic presentation of these fields an unfortunate and counterproductive view developed, propounded by a group of Arabists who have the tendency to assign only to this phase, viz. the first half of the 3rd/9th century, the beginning of the codification of the literary, poetic, legal, historical, theological and philological texts of all earlier generations since pre-Islamic times. The exponents of this tendency claim to have convinced themselves that the authors of the works emerging in this period were the first to commit to writing the materials that had been handed down orally until then. By contrast, it must be held that the written products of this period [15] were mainly aimed at expanding and enhancing the systematic structure, as well as the selection and interpretation; that is to say, they were meant to be supplements in the widest sense and, though they brought forth new literary genres,

[46] H. Suter, *Über die Geometrie der Söhne des Mûsâ ben Schâkir*, in: Bibliotheca Mathematica (Stockholm) 3rd series, 3/1902/259–272, esp. p. 272 (reprint in: Islamic Mathematics and Astronomy, vol. 76, pp. 137–150, esp. p. 150); F. Sezgin, op. cit., vol. 5, p. 34, 249.

[47] v. Moritz Cantor, *Vorlesungen über Geschichte der Mathematik*, vol. 1, 3rd ed., Leipzig 1907, p. 733; F. Sezgin, op. cit., vol. 5, pp. 34–35, 251.

[48] v. F. Sezgin, op. cit., vol. 7, pp. 241-261.

[49] v. ibid, vol. 7, p. 242.

[50] v. ibid, vol. 7, p. 242.

[51] v. K. Schneider-Carius, *Wetterkunde, Wetterforschung*, Munich 1955, pp. 82-87; F. Sezgin, op. cit., vol. 7, pp. 242-243.

[52] v. ibid, vol. 7, p. 241.

[53] v. ibid, vol. 7, p- 304.

were intended to continue preceding literary traditions. Characteristic in this sense were the mathematical disputations between the atomists and their adversaries carried out with all virtuosity in theological-dialectical works in the second half of the 2nd/8th century and during the following century.[54]

The second half of the 3rd/9th century saw an increase in the signs of creative independence. In the field of astronomy significant progress was made in gnomonics and in the practical study of construction methods for sundials which had started already at the beginning of the century. Al-Kindī determined the azimuth in a different way to his predecessor Ptolemy. His younger contemporary, al-Māhānī, who dealt briefly with the same problem in the second half of the 3rd/9th century, departed even more than al-Kindī from descriptive geometry and used for the most part a purely graphic method. The computational method for the determination of the azimuth and shadow lengths required for the point-by-point construction of sundials gained more and more importance over the graphic method from the last quarter of the 3rd/9th century. Ṯābit b. Qurra and his grandson Ibrāhīm b. Sinān, proponents of this school of a computational solution, discovered the curvature of the hour lines, drawn point-by-point on horizontal dials. The proof devised by Ibrāhīm is the same as that by Christoph Clavius[55] (1537-1612) and Jean-Baptist Delambre (1749-1822).[56]

Ṯābit b. Qurra (d. 288/901) contributed an improved value for the precession of the equinoxes. It is 1° in 66 years, i.e. 55" in one year, as compared to 1° in one hundred years or 36" in one year for Ptolemy and Hipparch. Subsequent astronomers introduced further improvements, so that Naṣīraddīn aṭ-Ṭūsī (d. 672/1274) was able to calculate a value of 1° in 70 years or 51" per year which comes already very close to the value of 1° in 72 years held in modern times.[57]

In the course of his observations, Ṯābit b. Qurra was the first to notice that the sun's apogee moves in the same direction as the signs of the zodiac.[58] A precise definition of the extremes of acceleration and deceleration in this motion was arrived at by al-Bīrūnī towards the end of the 4th/10th century.[59] The value for the apogee's progression was determined towards the end of the 5th/11th century by the Andalusian astronomer Ibrāhīm b. Yaḥyā az-Zarqālī with 1° in 279 years, corresponding to 12.09" in one year, which is quite close to the modern value of 11.46".[60]

Towards the end of the 3rd/9th century, Abu l-ʿAbbās al-Īrānšahrī defended the possibility of an annular solar eclipse against Ptolemy and expressed the view that a total solar eclipse can occur only at a medium distance and not at the maximum distance of the Sun from the Earth.[61] In the Occident, an annular eclipse was observed by Chr. Clavius in the year 1567.[62]

[16] The geographer Aḥmad b. ʿUmar Ibn Rustah,[63] who flourished in the second half of the 3rd/9th century, mentions amongst the cosmological and astronomical theories known to him, the notion that the Earth was not situated in the centre of the universe and that it was not the Sun and the spheres which rotate but the

[54] v. F. Sezgin, op. cit., vol. 5, pp. 29-30.

[55] v. Cantor, *Vorlesungen über Geschichte der Mathematik,* op. cit., vol. 2, p. 556.

[56] v. F. Sezgin, op. cit., vol. 6, pp. 23-24.

[57] v. ibid, vol. 6, p. 26.

[58] al-Masʿūdī, *at-Tanbīh wa-l-išrāf*, Leiden 1893, p. 222; E. Wiedemannn, *Über Ṯâbit ben Qurra, sein Leben und Wirken,* in: Sitzungsberichte der Physikalisch-medizinischen Sozietät (Erlangen) 52-53/1920-21/189-219 (reprint in: *Aufsätze zur arabischen Wissenschaftsgeschichte,* vol. 2, pp. 548-578; exp. p. 565); F. Sezgin, op. cit., vol. 6, p. 163.

[59] v. F. Sezgin, op. cit., vol. 6, p. 263.

[60] v. ibid, vol. 6, p. 27.

[61] v. ibid, vol. 6, p. 173.

[62] v. Matthias Schramm, *Ibn al Hayṯams Weg zur Physik,* Wiesbaden 1963, p. 27.

[63] *Kitāb al-Aʿlāq an-nafīsa*, Leiden 1891, pp. 23-24.

Earth. We would very much like to know where this vision of a heliocentric system came from. He further reports on a theory to the effect that the universe is infinite and that the Earth, as part thereof, is in an infinite falling motion.

The invention of the first astronomical instruments in the Arab-Islamic culture area occurred in the last quarter of the century. One of these was the spherical astrolabe, the invention of which is attributed to Ǧābir b. Sinān al-Ḥarrānī[64] (infra vol. II, 120 f.). His contemporary al-Faḍl b. Ḥātim an-Nairīzī claims to be the first to have invented instruments with which the distance between objects situated in the atmosphere or projecting from the Earth's surface can be measured.[65]

The mathematician and astronomer Muḥammad b. ʿĪsā al-Māhānī (lived possibly up to 275/888) took a crucial step forward in the history of mathematics when he reduced a problem which could not be solved with a pair of dividers and a ruler to an equation of the third degree. However, he did not succeed in solving the equation.[66] Al-Māhānī was also the first mathematician to arrive at a method of using the law of the spherical cosine for the mathematical determination of the azimuth when he calculated one of the angles of a spherical triangle from its sides. As Paul Luckey[67] was able to demonstrate in 1948, al-Māhānī was a forerunner of Johannes Regiomontanus (1436-1476) in this respect.

In the second half of the 3rd/9th century Ṯābit b. Qurra achieved outstanding results not only in astronomy but in mathematics as well. He generalized the theorem of Pythagoras for all triangles; in the Occident, however, the relevant theorem bears the name of John Wallis (1616-1703).[68] Without being aware of the results already achieved by Archimedes in this area, Ṯābit made use of infinitesimal calculus in his two treatises on the quadrature of the parabola and on the cubature of the paraboloid. His quadrature of the parabola corresponds to the calculation of the integral ${}_0\int^a \sqrt{px}\,dx$. Through a brilliant step which he applied there, "the summation of integrals that had fallen into oblivion was revived; and with its help Ibn Qurra calculated, indeed for the first time, an integral of the power x^n, for a fractional exponent, namely , where he, again for the first time, undertook ${}_0\int^a x^{1/2}\,dx$ the division of the integration interval into unequal units. In the middle of the 17th century, P. de Fermat undertook the quadrature of the curves $y = x^{m/n}$ for $m/n < 1$ »through a similar procedure, where he divided for the abscissas into units forming a geometrical progression."[69] Ṯābit's procedure for the calculation of the volume of paraboloids also differs substantially from that of Archimedes. His calculation of the volumes of domes with pointed or depressed crowns gained [17] by the rotation of a parabola around a secondary axis is also novel, whereas Archimedes merely dealt with the rotation of paraboloids with an axis of rotation identical to the axis of the parabola.[70]

His contemporary Ḥabaš al-Ḥāsib already applied a kind of iterative algorithm in the calculation of the lunar parallax. The equation in question resembles the one later introduced by Johannes Kepler (1571-1630) in connection with his theory of planetary motion.[71] Ḥabaš

[64] v. F. Sezgin, op. cit., vol. 6, p. 162.

[65] v. ibid., vol. 5, p. 268-269.

[66] v. ibid., vol. 5, p. 260.

[67] v. his *Beiträge zur Erforschung der islamischen Mathematik. I. Die ältere Gnomonik,* in: Orientalia (Rome), N.S. 17/1948/490-510, esp. pp. 502-503 (reprint in: Islamic Mathematics and Astronomy, vol. 96, pp. 46-66, esp. pp. 58-59).

[68] v. A. Sayılı, *Sâbit ibn Kurra'nın Pitagor teoremini tamimi,* in: Belleten (Ankara) 22/1958/527-549; idem, *Thâbit ibn Qurra's Generalization of the Pythagorean Theorem,* in: Isis 51/1960/35-37; F. Sezgin, op. cit., vol. 5, p. 266.

[69] v. A. P. Juschkewitsch, *Geschichte der Mathematik im Mittelalter,* Basel 1964, p. 291; F. Sezgin, op. cit., vol. 5, pp. 38, 265-266.

[70] v. F. Sezgin, op. cit., vol. 5, pp. 38, 266.

[71] v. E. S. Kennedy, W. R. Transue, *A medieval itera-*

was perhaps also the first mathematician and astronomer to prepare a table of cosecants (*quṭr aẓ-ẓill*), comprising 1°-90°;[72] yet his Arabic successors did not emulate him as they obviously realized that secants and cosecants were dispensable for their trigonometric calculations. In the Occident, Nicolaus Copernicus (1473-1543) was the first to compile tables of secants, yet here too they disappeared from trigonometry from the 17th century onwards after their dispensability became obvious.[73]

A comparison between the work on algebra by Abū Kāmil Šuǧāʿ b. Aslam[74] (written apparently in the last quarter of the 3rd/9th century) and those of his predecessors (which appeared in the sixties and seventies) shows that this subject must have undergone a rapid development in the regions of Islam during the second half of the century. Even though Abū Kāmil, like his predecessors, does not go beyond linear and quadratic equations, it becomes obvious in his case that he had traversed a long distance on the way towards arithmetisation and that the theoretical part had grown copiously in his work. In the application of the procedure of geometrical proof, we find him abandoning the demand for faithfulness to dimensions:[75] He speaks of proportions but makes no distinction between commensurable and incommensurable units. With him the reluctance to tackle the irrational, noticeable among the Greeks, disappears. To the three quantities enumerated by al-Ḫwārizmī–numbers, roots and squares–he adds the unknowns up to the seventh power.[76]

Together with al-Ḫwārizmī, Abū Kāmil belongs to those Arab-Islamic scholars who brought about a profound effect in the Occident through Hebrew and Latin translations of their works. "The longest lasting influence on subsequent Occidental mathematicians he exerted through the mediation of Leonardo of Pisa, who made ample use of Abū Kāmil's 'algebra' in his *Liber abaci.*" Leonardo adopted some problems even in the same wording.[77]

Medicine and pharmacy also developed remarkably in the second half of the 3rd/9th century. Abū Bakr ar-Rāzī (b. ca. 251/[18] 865; d. 313/925) was the most important among the numerous physicians of that period. Through his extensive *Kitāb al-Ḥāwī* (Latin: *Liber continens*) and numerous other works, he not only influenced the medicine and pharmacy of his own cultural area but also became, via translations of many of his books into Hebrew and Latin, an undisputed authority in Western medicine right up to the 17th century.[78] Moreover, after Ǧābir b. Ḥaiyān, he was the next, as far as we know, to have criticized several points of Galen's medicine. His surviving "Doubts" on Galen[79] are of great interest for the history of medicine.

tive algorism, in: The American Mathematical Monthly (Menasha, Wisc.) 63/1956/80-83; E. S. Kennedy, *An early method of successive approximation,* in: Centaurus (Copenhagen) 13/1969/248-250); A. P. Juschkewitsch, op. cit., p. 324; F. Sezgin, op. cit., vol. 5, p. 276.

[72] K. Schoy, *Über den Gnomonschatten und die Schattentafeln der arabischen Astronomie. Ein Beitrag zur arabischen Trigonometrie nach unedierten arabischen Handschriften,* Hanover 1923, pp. 14-15 (reprint in: Islamic Mathematics and Astronomy, vol. 25, p. 187 ff., esp. pp. 200-201); J. Tropfke, *Geschichte der Elementar-Mathematik,* vol. 5, 2nd ed., p. 29; A. P. Juschkewitsch, op. cit., p. 309; F. Sezgin, op. cit., vol. 5, pp. 39, 276.

[73] J. Tropfke, op. cit., vol. 5, pp. 29-30; F. Sezgin, op. cit., vol. 5, p. 39.

[74] v. F. Sezgin, op. cit., vol. 5, pp. 277-281.

[75] see A. P. Juschkewitsch, op. cit., p. 223; F. Sezgin, op. cit., vol. 5, pp. 39, 278-279.

[76] v. F. Sezgin, op. cit., vol. 5, p. 40.

[77] Josef Weinberg, *Die Algebra des Abū Kāmil Šoǧāʿ ben Aslam,* Munich 1935, p. 16 (reprint in: Islamic Mathematics and Astronomy, vol. 23, p. 107 ff., esp. p. 122); F. Sezgin, op. cit., vol. 5, p. 280.

[78] v. F. Sezgin, op. cit., vol. 3, p. 274 ff.

[79] v. ibid, vol. 3, p. 77.

Julius Hirschberg,[80] the eminent authority on Arabic ophthalmology, drew attention to the fact that ar-Rāzī in his *Kitāb aṭ-Ṭibb al-Manṣūrī*, was the first to speak of the contraction of the pupil upon exposure to light. Not only from the medical point of view but also from the history of optics, it is of epochal significance that ar-Rāzī in his treatise on optical perception and in his critique of Galen refuted Euclid's and Galen's theory of vision, according to which the process of seeing relies on rays emanating from the eye.[81]

In the field of chemistry-alchemy, ar-Rāzī, building upon Ǧābir's work, produced a body of literature mainly to serve practical requirements with brief descriptions of the substances, apparatuses and processes.

At the same time, i.e., in the second half of the 3rd/9th century, in the field of geography, a distinct anthropogeography developed from the genre of histories of cities and conquests that had already emerged in the preceding period. Examples are the *Kitāb al-Amṣār wa-ʿaǧāʾib al-buldān*[82] by the natural philosopher and polymath ʿAmr b. Baḥr al-Ǧāḥiẓ (d. 255/868), the *Kitāb al-Masālik wa-l-mamālik*[83] by ʿUbaidallāh b. ʿAbdallāh Ibn Ḫurradāḏbih (d. after 289/902) and the *Kitāb al-Buldān*[84] by Aḥmad b. Isḥāq al-Yaʿqūbī (d. around 300/913).

In the field of physics and technology the name of the Andalusian ʿAbbās b. Firnās (d. 274/887) shall be mentioned. Numerous physical and astronomical inventions are attributed to this versatile scholar. He gained lasting fame by an attempt to fly, which is said to have been successful over a certain distance.[85]

The development achieved in the other disciplines of science at that time was paralleled in historiography by the emergence of extensive, chronologically arranged histories of the world and of single realms. The best known and most significant surviving work of this genre is doubtless the *Kitāb Aḫbār ar-rusul wa-l-mulūk* by Muḥammad b. Ǧarīr aṭ-Ṭabarī (224/839-310/923).[86] Arabist research has had access to this voluminous book since the commendable edition by M. J. de Goeje in 15 volumes (1879-98). However, the manner in which the sources are cited here meets with incomprehension and little sympathy among modern readers. The chains of transmission that accompany every account are not recognised as references to [19] written sources or authorized transmitters of books from earlier generations, but are considered as fictitious names of suppliers of oral information which had become accessible in whatever way. Thus not only an unjustifiably negative attitude towards the contents of these reports arises but the universal historiography also fails to realise the knowledge of the strict methods[87] of citation of sources cultivated in the first centuries of Islam.

The development in the field of lexicography in this period is distinguished by a comprehensive treatment of single topics which subsequently contributed to the production of extensive alphabetically and thematically arranged dictionaries in the 4th/10th century. I would like to mention the book of plants (*Kitāb an-Nabāt*) by Abū Ḥanīfa ad-Dīnawarī[88] (d. ca

[80] *Geschichte der Augenheilkunde,* vol. 2: *Geschichte der Augenheilkunde im Mittelalter,* Leipzig 1908 (= Graefe-Saemisch, *Handbuch der gesamten Augenheilkunde,* vol. 13), p. 105; F. Sezgin, op. cit., vol. 3, pp. 18, 277.

[81] v. F. Sezgin, op. cit., vol. 3, pp. 8, 277.

[82] A heavily abridged summary of this work entitled *Kitāb al-Auṭān wa-l-buldān* was edited by Ch. Pellat, *al-Ǧāḥiẓ rāʾid al-ǧuġrāfīya al-insānīya,* in: al-Ma·riq (Beirut) 60/1966/169-205.

[83] Edited and translated into French by M. J. de Goeje, Leiden 1889 (reprint: Islamic Geography, vol. 39).

[84] Edited by M. J. de Goeje, Leiden 1892 (reprint: Islamic Geography, vol. 40).

[85] .v. F. Sezgin, op. cit., vol. 2, pp. 674-675; vol. 6, p. 158.

[86] v. ibid, vol. 1, pp. 323-329; English translation in 39 volumes, *The History of al-Ṭabarī*, New York: State University 1985-1998 (Bibliotheca Persica).

[87] v. F. Sezgin, op. cit., vol. 1, pp. 53-84, 237-256.

[88] v. ibid, vol. 4, pp. 338-343.

282/895) as an interesting example of this genre. The surviving parts of this book, originally comprising 7 volumes, show clearly how far and how rapidly a branch of knowledge hitherto cultivated by the Greeks could already develop, in complete independence from the latter, amongst Arab philologists before the end of the 3rd/9th century. A study[89] conducted exclusively on the basis of fragments of this book as cited in later dictionaries shows that Abū Ḥanīfa's botanical descriptions are equal to those of the *Materia medica* by Dioscurides. According to Bruno Silberberg, the descriptions prepared by Dioscurides had a different motivation from those in the *Kitāb an-Nabāt* of Abū Ḥanīfa. The purpose of the former was to help the reader in the identification of herbs in the field, i.e. purely practical, while Abū Ḥanīfa's presentation seems to have been inspired by a delight in the manifold varieties of plant morphology. In those days, Silberberg[90] would still wonder: "How could the people of Islam reach in this respect the level of the brilliant Greeks or even surpass them at such an early period of their literature?"

Abū Ḥanīfa's book bears witness to the use of a scientific botanical terminology; he "knows a lot of specialised expressions for the diverse features of plants which in an unbiased reader evokes the impression that they were part of a scientific nomenclature created for the sake of greater precision."[91] He displays an advanced scientific-morphological attitude,[92] is familiar with the observation and description of physiological aspects[93] and illustrates "complicated shapes in plants by comparison with familiar types."[94]

Amongst the examples of the development of sciences in this period, we may, lastly, mention the beginning of rhetoric (*ʿilm al-badīʿ*) and of poetics (*ʿilm aš-šiʿr*) towards the end of the 3rd/9th century. Although Aristotle's works on these subjects were available in the Arab-Islamic culture area through translations, the original Arabic theory of literature seems to have been hardly influenced by it. The two works by Aristotle were, as part of the *Organon,* of interest merely to philosophers and logicians.[95]

[20] The 4th/10th Century

In the 4th/10th century some Arabic astronomers asked whether the obliquity of the ecliptic was constant or subject to change. Ibrāhīm b. Sinān b. Ṯābit (d. 335/946) came to the conclusion that it was not constant. About fifty years later, Ḥāmid b. al-Ḫiḍr al-Ḫuǧandī convinced himself, after many years of observations in an observatory built for the specific purpose of finding the answer to this problem which featured a sextant with a radius of about 67 feet, that the obliquity of the ecliptic decreases continuously (infra vol. II, 25). The discussion of the question concerning the Earth's rotation had already started towards the end of the 3rd/9th century–and apparently a heliocentric system had also been taken into consideration;

[89] Bruno Silberberg, *Das Pflanzenbuch des* Abû Ḥanîfa Aḥmed ibn Dâ'ûd ad-Dînawarî. *Ein Beitrag zur Geschichte der Botanik bei den Arabern,* in: Zeitschrift für Assyrologie und verwandte Gebiete (Strasbourg), 24/1910/225-265, 25/1911/39-88, esp. pp. 43-44 (reprint in: Natural Sciences in Islam, vol. 18, pp. 117-208, esp. pp. 163-164); F. Sezgin, op. cit., vol. 4, p. 339.

[90] B. Silberberg, op. cit., p. 44 (reprint p. 164).

[91] ibid, pp. 45-47 (reprint pp. 165-167).

[92] ibid, p. 67 ff. (reprint p. 187 ff.).

[93] ibid, pp. 65--66 (reprint pp. 185-186).

[94] ibid, p. 69 (reprint p. 189).

[95] v. Seeger A. Bonebakker, *Reflections on the Kitāb al-Badīʿ of Ibn al-Muʿtazz,* in: Atti del Terzo Congresso di Studi Arabi e Islamici, Ravello 1-6 settembre 1966, Naples 1967, pp. 191-209; Wolfhart Heinrichs, *Arabische Dichtung und griechische Poetik. Ḥāzim al-Qarṭāǧannīs Grundlegung der Poetik mit Hilfe aristotelischer Begriffe,* Beirut 1969, p. 16; idem, *Poetik, Rhetorik, Literaturkritik, Metrik und Reimlehre,* in: Grundriß der arabischen Philologie, vol. 2, Wiesbaden 1987, pp. 177-207, esp. pp. 188-190.

towards the end of the century this idea found a convinced advocate in the person of Aḥmad b. Muḥammad as-Siǧzī (infra vol. II, 16). Ǧaʿfar b. Muḥammad b. Ǧarīr, a contemporary of as-Siǧzī, also believed in the Earth's rotation. Both scholars constructed astrolabes according to this view.[96]

At the same time, the fundamental work on fixed star astronomy was composed by ʿAbdarraḥmān aṣ-Ṣūfī in which he largely revised and updated the preliminary work by Hipparchus and Ptolemy (infra vol. II, 17).

In the field of astronomy we should also mention the remarkable invention of an instrument known by the name *Zīǧ aṣ-ṣafāʾiḥ*, which Abū Ǧaʿfar Muḥammad b. al-Ḥusain al-Ḫāzin[97] (1st half of the 4th/10th c.) constructed in order to be able to determine the longitudes of the planets directly by means of an instrument, without any arithmetical computations. We can trace the lasting effect of this instrument until the 16th century more clearly in Europe (where it was known under the name of equatory, v. infra vol. II, 173 ff.) than in the Islamic world.

Towards the end of the century an entirely new element widened the scope of astronomical observations, when the refraction of light by the atmosphere was taken into account and attempts were made to determine it quantitatively.[98]

In the field of mathematics great success was achieved in the 4th/10th century. Thus the already mentioned mathematician and astronomer Abū Ǧaʿfar al-Ḫāzin was the first to succeed in solving an equation of the third order with the help of conic sections. Further progress in the extraction of cube roots was made in the second half of the century. Thanks to the work of H. Suter[99] and P. Luckey,[100] we know of two methods by the two mathematicians Kūšyār b. Labbān[101] and Abu l-Ḥasan an-Nasawī[102] who were perhaps indebted to the established methods of the Chinese and Indians, but surpassed their predecessors. One of the two methods was the formula $\sqrt{a^2+b} \approx a + b/2a$ that can be derived from the binomial theorem for $b<a$, which appears again in the first half of the 13th century in the work of Leonardo Pisano. The second is an approximation formula. As P. Luckey[103] demonstrated, this is in fact the familiar Ruffini-Horner method of approximative solutions for algebraic equations.[104] Muḥammad b. al-Ḥasan al-Karaǧī[105], [21] one of the most eminent mathematicians of the time, already knew a formula for the fourth power. His contemporary Abu l-Wafāʾ Muḥammad b. Muḥammad al-Būzaǧānī[106] wrote a treatise on the extraction of roots up to and including the seventh power.[107] Around the middle of the century, Aḥmad b. Ibrāhīm al-Uqlīdisī dealt with decimal fractions. According to his own statements, he was also the first to write on cubic numbers and cube roots.[108]

Another one of the great mathematicians of this period, who with their contributions defined the standard of the subject in the 4th/10th centu-

96 v. F. Sezgin, op. cit., vol. 6, pp. 224-225.

97 v. ibid, vol. 5, pp. 298-299, 305-307; vol. 6, pp. 189-190.

98 v. ibid, vol. 5, p. 229.

99 *Über das Rechenbuch des Alî ben Aḥmed el-Nasawî*, in: Bibliotheca mathematica (Leipzig, Berlin) 3rd series 7/1906–7/113–119 (reprint in: Islamic Mathematics and Astronomy, vol. 82, pp. 361–367).

100 *Die Ausziehung der n-ten Wurzel und der binomische Lehrsatz in der islamischen Mathematik*, in: Mathematische Annalen (Berlin) 120/1948/217–274 (reprint in: Islamic Mathematics and Astronomy, vol. 56, pp. 11–68).

101 v. F. Sezgin, op. cit., vol. 5, pp. 343–345.

102 v. ibid., vol. 5, pp. 345–348.

103 *Die Ausziehung der n-ten Wurzel*, op. cit., pp. 220–221 (reprint. pp. 14–15).

104 v. F. Sezgin, op. cit., vol. 5, p. 43.

105 v. ibid., vol. 5, pp. 325–329.

106 v. ibid., vol. 5, pp. 321–325.

107 v. ibid., vol. 5, p. 43.

108 v. ibid., vol. 5, p. 296.

ry, was Abū Sahl Waiǧan b. Rustam al-Kūhī.[109] Continuing the work of his predecessors in the field of infinitesimal calculus, he calculated the volume of parabolic domes by a simple method.[110] Among the contemporary attempts to find solutions for geometric problems leading to equations of the third order, Abū Sahl solved the problem of finding a segment of a sphere the volume of which equals that of a given segment and the surface of which equals that of another given segment. "He solves them with the help of an equilateral hyperbola and a parabola, whose points of intersection are used to measure the unknown quantity. He also includes a discussion of the precise conditions under which the problem can be solved."[111] Abū Sahl al-Kūhī also left us an elegant solution for the problem of trisecting an angle with the help of a hyperbola.[112] In the course of his intense occupation with curves of the third degree, he invented the "perfect compass" (*barkār tāmm*) for drawing conic sections.[113] He also sought a geometrical answer to the physical-geometrical question of whether an infinite continuous motion was possible on a finite straight line.[114] His affirmative answer and the method used recall the approach by Giovanni Battista Benedetti[115] (1530-1590). Maybe Abū Sahl intended, without saying so, to refute Aristotle, who had expressed the view that a continuous motion on a finite line was impossible.[116]

The great achievements in mathematics of this period also include those in the field of plane and spherical trigonometry even though they are usually regarded as part of astronomy. The first systematic treatment of elements of trigonometry is to be found in the work of Abu l-Wafā' Muḥammad b. Muḥammad al-Būzaǧānī[117] (328/940 - ca. 388/998). He treats the trigonometric functions uniformly and introduces a new method for the calculation of tables by a method of interpolation, with which [22] he calculates the tables of sines, tangents and cotangents. His sine table has an interval of 15 minutes.[118] Abu l-Wafā', at the same time as his contemporaries Ḥāmid b. Ḫiḍr al-Ḫuǧandī and Abū Naṣr Manṣūr b. ʿAlī Ibn ʿIrāq, claims priority in the discovery of the fundamental law of spherical trigonometry (infra vol. III, 133 ff.). This has primarily to do with the determination of the sides of a spherical triangle from its angles. It appears that Abu l-Wafā' really has the priority here. Moreover, he was also the first mathematician to attempt a solution of geometric problems with a pair of dividers of fixed gauge.[119]

In the field of medicine, it should be emphasized that the level reached in this area led to the almost simultaneous yet independent publication of the first handbooks covering the entire

[109] v. ibid., vol. 5, pp. 314-321.

[110] v. H. Suter, *Die Abhandlungen Thâbit b. Ḳurras und Abû Sahl al-Kûhîs über die Ausmessung der Paraboloide,* in: Sitzungsberichte der Physikalisch-medizinischen Sozietät (Erlangen) 48-49/1916-17/186-227, esp. p. 222 (reprint in: Islamic Mathematics and Astronomy, vol. 21, pp. 68-109, esp. p. 104).

[111] v. M. Cantor, *Vorlesungen über Geschichte der Mathematik,* vol. 1, 3rd ed. 1907, p. 749, following F. Woepcke, *L'algèbre d'Omar Alkhayyâmî,* Paris 1951, pp. 103-114 (reprint in: Islamic Mathematics and Astronomy, vol. 56, pp. 1-206, esp. pp. 127-138); F. Sezgin, op. cit., vol. 5, p. 315.

[112] v. Aydın Sayılı, *The trisection of the angle by Abû Sahl Wayjan ibn Rustam al-Kûhî (fl. 970-988),* in: Belleten (Ankara), 26/1962/96-697; F. Sezgin, op. cit., vol. 5, p. 317.

[113] v. F. Sezgin, op. cit., vol. 5, p. 317; infra vol. III, p. 151.

[114] v. Aydın Sayılı, *A short article of Abû Sahl Waijan ibn Rustam al Qûhî on the possibility of infinite motion in finite time,* in: Actes du VIIIe Congrès international d'histoire des sciences, Florence - Milan 3-9 septembre 1956, Florence 1958, vol. 1, pp. 248-249; idem, in: Belleten (Ankara), 21/1957/489-495.

[115] On the method, see Kurd Lasswitz, *Geschichte der Atomistik vom Mittelalter bis Newton,* vol. 2, Leipzig 1890 (reprint Hildesheim 1963), pp. 15-16.

[116] On Aristotle's view, see ibid, p. 19.

[117] v. F. Sezgin, op. cit., vol. 5, pp. 321-325.

[118] v. A. P. Juschkewitsch, *Geschichte der Mathematik im Mittelalter,* pp. 309-310.

[119] v. F. Sezgin, op. cit., vol. 5, p. 46.

field of medicine in world literature. These are the *Kāmil aṣ-ṣināʿa aṭ-ṭibbīya* by ʿAlī b. al-ʿAbbās al-Maǧūsī,[120] *at-Taṣrīf li-man ʿaǧiza ʿan at-taʾlīf* by Abu l-Qāsim Ḫalaf b. ʿAbbās az-Zahrāwī[121] and *al-Muʿālaǧāt al-Buqrāṭīya* by Abu l-Ḥasan Aḥmad b. Muḥammad aṭ-Ṭabarī[122]. In the eleventh century, the book written by ʿAlī b. al-ʿAbbās al-Maǧūsī was translated into Latin as *Liber pantegni* by Constantinus Africanus in Salerno and circulated in Europe for centuries under the authorship of the translator. In the year 1127, it appeared once more in a translation by Stephanus of Antioch.[123]. The 30th chapter of the *at-Taṣrīf* by az-Zahrāwī, devoted to surgery was translated into Latin by Gerard of Cremona in the 12th century. Its 28th chapter, dealing with materia medica, and the 30th about surgery belonged to the most widely circulated books of Arabic medicine in Europe. The third title, *al-Muʿālaǧāt al-Buqrāṭīya,* did not reach Europe before modern times.

Amongst the most important achievements of this century should also be counted the book *Maṣāliḥ al-abdān wa-l-anfus* by Abū Zaid Aḥmad b. Sahl al-Balḫī[124] (d. 322/934) in whom we encounter an early exponent of psychosomatics. [125] One of the great advances in the medicine of that century was made in ophthalmology and is associated with the name of ʿAmmār b. ʿAlī al-Mauṣilī. In his book, written towards the end of the century, Julius Hirschberg[126] found particularly interesting "his clear and captivating descriptions of six cataract operations, which remain highly attractive even to the modern reader." Hirschberg goes on to add that in Greek literature there was nothing comparable and in modern literature it was only in the 18th century "that we encounter such precise and remarkable medical case histories again." ʿAmmār's most important operation, Hirschberg adds, was [23] the radical operation of the soft cataract by suction with a metal syringe he had devised for that purpose. Remarkable was also the removal of the iris prolapse while retaining the faculty of vision, "whereas before him the Greeks and Arabs had undertaken this operation only for the improvement of looks but not for the improvement of sight."[127]

In the 4th/10th century, the previous development in geography led to the appearance of an anthropogeography such as developed in Europe only in the 19th century. This genre of Arab-Islamic geography with its stencil-like didactic maps may have been influenced by the Sassanid-Persian cultural area but appears completely autochthonous in its development. It was represented by Abū Zaid al-Balḫī, al-Ǧaihānī, al-Iṣṭaḫrī, Ibn Ḥauqal and al-Maqdisī (al-Muqaddasī). The youngest of these, al-Maqdisī, was described as "the greatest geographer ever" by the arabist Alois Sprenger around the middle of the 19th century after

[120] v. F. Sezgin, op. cit., vol. 3, pp. 320-322; facsimile edition in three volumes by the Institut für Geschichte der Arabisch-Islamischen Wissenschaften, Frankfurt 1985.

[121] v. ibid, vol. 3, pp. 323-325; facsimile edition in two volumes by the Institut für Geschichte der Arabisch-Islamischen Wissenschaften, Frankfurt 1986.

[122] v. ibid, vol. 3, pp. 307-308; facsimile edition in two volumes by the Institut für Geschichte der Arabisch-Islamischen Wissenschaften, Frankfurt 1990.

[123] v. Heinrich Schipperges, *Die Assimilation der arabischen Medizin durch das lateinische Mittelalter,* Wiesbaden 1964, p. 34 ff.; Danielle Jacquart, Françoise Micheau, *La médicine arabe et l'occident médiéval,* Paris 1990, p. 96 ff.; Charles Burnett, Danielle Jacquart (eds.), *Constantine the African and ʿAlī Ibn al-ʿAbbās al-Maǧūsī. The Pantegni and related texts.* Leiden 1994 (contains 16 contributions).

[124] v. F. Sezgin, op. cit., vol. 3, p. 274.

[125] The two extant manuscripts of his book were brought out separately in facsimile by the Institut für Geschichte der Arabisch-Islamischen Wissenschaften, Frankfurt 1984 and 1998; on this Zahide Özkan, *Die Psychosomatik bei Abū Zaid al-Balḫī (gest.* 934 *A.D.),* Frankfurt 1990 (reprint: Islamic Medicine, vol. 98).

[126] *Geschichte der Augenheilkunde im Mittelalter,* op. cit., p. 54.

[127] J. Hirschberg, op. cit., p. 54; F. Sezgin, op. cit., vol. 3, p. 331.

he had discovered the first manuscript of al-Maqdisī's book (infra vol. III, 3f.) in India and studied it.

Amongst the most significant achievements of the century were also two fundamental works on the history of science. One of them is the "Catalogue" (*Fihrist*) by Muḥammad b. Abī Yaʿqūb Isḥāq Ibn an-Nadīm[128] (d. ca. 400/1010) which, under its modest title, aims to list the scientific literature of all known culture areas. Such a work on the history of science–that astonishes us with its capacity to survey the material on a broad scope and to deal with foreign cultures objectively–would be inconceivable without an older tradition that made its appearance possible. We are reasonably familiar with this tradition today.[129] We might also think, for instance, of the works by the widely-travelled encyclopaedist ʿAlī b. al-Ḥusain al-Masʿūdī[130] (d. ca 345/956), which I see as an attempt to describe all known cultures and civilizations past and present.[131] Ibn an-Nadīm himself quite frequently offers interesting clues that help us understand how his book came about. In the second part of his 9th treatise on the cultures of India and China,[132] he cites a passage about the religions and sects of India and their sacred places from a book written by an envoy whom the statesman Yaḥyā b. Ḫālid al-Barmakī (d. 190/805) had sent to India to report on its religions and to bring back medical drugs.

The second fundamental work of this period on the history of science was written in 377/987, the same year as Ibn an-Nadīm wrote his book. It is the history of medicine (*Ṭabaqāt al-aṭibbāʾ wa-l-ḥukamāʾ*) by the Andalusian physician Sulaimān b. Ḥassān Ibn Ǧulǧul[133] which likewise is not restricted to the Islamic period. Comparing this work with the treatise written by Isḥāq b. Ḥunain (d. 298/910) on the "History of Physicians" (*Taʾrīḫ al-aṭibbāʾ*),[134] which appeared half a century earlier and was based on a pamphlet by the Alexandrian Johannes Grammatikos (1st half of the 6th century CE), we may understand how far the historiography of science had advanced in this short period and the dimension of universality it had gained.

[24] I will have to pass over the development of humanities in the fields of philology, history, philosophy and the study of literature, to the details and importance of which Adam Mez devoted his *Renaissance des Islâms,*[135] which appeared in 1922. I restrict myself to drawing the attention to one unique cultural-historic achievement of the 4th/10th century, namely the "Book of Songs" (*Kitāb al-Aġānī*) in twenty-four volumes by Abu l-Faraǧ Aḥmad b. al-Ḥusain al-Iṣfahānī[136] (d. 356/967). It is the extension and supplement of a collection of one hundred selected song compositions compiled by three famous musicians upon commission by Caliph Hārūn ar-Rašīd which was subsequently revised and augmented[137] by the great musician and writer Isḥāq b. Ibrāhīm al-Mauṣilī[138] (b. 150/767, d. 235/850). The monumental work by Abu l-Faraǧ al-Iṣfahānī follows the tradition of his predecessors whose works it eclipsed and in the course of time caused to fall into oblivion. It provides not only information about the compositions[139] of the court

[128] v. F. Sezgin, op. cit., vol. 1, pp. 385-388.

[129] ibid, vol. 1, pp. 383-388.

[130] v. ibid, vol. 1, pp. 332-336; vol. 6, pp. 198-203; vol. 7, pp. 276-277.

[131] I have written on this in the section on anthropogeography of the *Geschichte des arabischen Schrifttums,* which is still in manuscript.

[132] Ibn an-Nadīm, *Fihrist*, p. 345–351, esp. p. 345.

[133] v. F. Sezgin, op. cit., vol. 3, pp. 309–310.

[134] v. F. Sezgin, op. cit., vol. 3, pp. 268.

[135] Mez died in 1917. The manuscript of his book, which he was not able to revise, was prepared for printing by Hermann Reckendorf and published in 1922 in Heidelberg.

[136] v. F. Sezgin, op. cit., t. 1, p. 378–382.

[137] v. ibid., vol. 1, p. 371.

[138] v. ibid., vol. 1, p. 378.

[139] v. Henry George Farmer, *The Song Captions in the*

musicians,[140] about their lives and the peculiarities of their music in theory and in practice, but also on the lyrics and their poets; beyond this, it mirrors the court life of the Umayyads and Abbasids and the intellectual circles that took part in it. The reader encounters here the cultivated life of an urbane society in whose intellectual interests priority is given to music, poetry and *belles letters*. It is a book the like of which is not found in any other culture.

The accomplishments of this century also included the creation of compound ink by the addition of soot–inspired by Chinese ink–to the traditional ink made of iron-gallic, which consisted of vitriol, extract of gallnut, gum arabic and water.[141]

The 5th/11th Century

During the 5th/11th century, the issue of eccentric or concentric planetary orbits that had first been brought up in the 4th/10th century developed into a critical discussion of the Ptolemaic model. The first attempts in this direction had already been made in the preceding century. Abū Ǧaʿfar Muḥammad b. al-Ḥusain al-Ḫāzin postulated a concentric model, rejecting the theory of eccentricity and epicycles which he replaced by the assumption of variations in each planetary orbit relative to the plane of the ecliptic.[142] Towards the end of the 4th/10th century, Abū Naṣr b. ʿIrāq[143] discussed the idea—proposed by his contemporaries—of elliptic planetary orbits with minute differences between the length of the two axes and the possibility of actual unsteadiness in the revolutions. He was, however, convinced of a constant and uniform motion and that the apparent irregularities and the observed variations in the diameter of the planetary orbits could be explained by eccentricity. [25] He apparently did not deem it necessary to retain any epicyclic motions.

The discussion took a new turn through Abū ʿAlī Ibn al-Haiṯam[144] (d. shortly after 432/1041). In his "Doubts on Ptolemy" he expresses his reservations by stating that Ptolemy, in his model for the explanation of planetary motion violated the fundamental principle of the uniformity of circular motion by introducing the equant, because the motion of the centre of the epicycles on the deferent cannot be uniform any more. Ibn al-Haiṯam was convinced[145] that Ptolemy had postulated this faulty model so that he would not have to give up his idea of the system of the planetary orbits and that he had introduced fictitious models with no basis in reality.[146]

Ibn al-Haiṯam's criticism of Ptolemy had a lasting influence on the succeeding generations that can be traced up to Copernicus. On the other hand, Ibn al-Haiṯam adopted the concept of the heavenly spheres as actual transparent structures from Ptolemy's ὑποθέσεις and elaborated upon it in his *Kitāb fī Haiʾat al-ʿālam*. This was clearly a backward step in the history of astronomy. The concept of tangible spheres, which was criticised about a hundred years later by Muḥammad b. Aḥmad al-Ḫaraqī (d. 533/1139),[147] remained relevant for centuries up to Newton's time.[148] On the other hand, the planetary kinematics (infra

Kibāb al-Aghānī al-Kabīr, in: Transactions of the Glasgow University Oriental Society 15/1953–54/1–10 (reprint in: The Science of Music in Islam, vol. 1, pp. 433–442).

[140] v. E. Neubauer, *Musiker am Hof der frühen Abbasiden*, Ph.D. Thesis Frankfurt 1965.

[141] I owe this information to Dr. Armin Schopen, who has been working on this subject matter for many years; see now his *Tinten und Tuschen des arabisch-islamischen Mittelalters. Dokumentation - Analyse - Rekonstruktion*, Göttingen, 2006, p. 61 ff.

[142] v. F. Sezgin, op. cit., vol. 6, p. 189.

[143] v. v. ibid, vol. 6, p. 243..

[144] v. F. Sezgin, op. cit, vol. 6, pp. 251 ff.

[145] ibid, vol. 6, p. 34..

[146] ibid, vol. 6, p. 87.

[147] v. ibid, vol. 6, p. 253.

[148] v. Karl Kohl, *"Über das Licht des Mondes. Eine Untersuchung von Ibn al Haitham*, in: Sitzungsberichte der Physikalisch-medizinischen Sozietät (Erlangen) 56-57/1924-25 (1926)/305-398, esp. p. 306 (reprint in: Islamic Mathematics and Astronomy, vol. 58, pp. 135-228, esp. p. 136).

II, 9f.) that Ibn al-Haiṯam elaborated in this connection were of great importance.

The polymath Abu r-Raiḥān Muḥammad b. Aḥmad al-Bīrūnī (362/973-440/1048), a contemporary of Ibn al-Haiṯam, took it upon himself to produce, besides numerous monographs on individual topics, a fundamental work on astronomy in which the development of the discipline up to his own time was to be treated systematically. He called it *al-Qānūn al-Masʿūdī* after the dedicatee Masʿūd b. Maḥmūd b. Sebüktigin who ruled from Ghazna. Al-Bīrūnī followed the Ptolemaic system to a large extent, yet he was aware that science had progressed in the course of time and that he himself was able to contribute something new to it. As an example of his achievements, his calculation of the distance of the apogee from the vernal equinox is mentioned. He determined the acceleration and deceleration of the motion in the perigee from the tables by differential analysis; thus he became one of the pioneers of infinitesimal calculus.[149]

One of the most significant achievements of the century was the expansion of mathematical geography into an independent discipline. Again it is al-Bīrūnī to whom this great credit goes. We learn from his work devoted to this topic, *Taḥdīd nihāyāt al-amākin li-taṣḥīḥ masāfāt al-masākin*, that during the 4th/10th century people in the eastern part of the Islamic world were fervently engaged in the determination of geographical coordinates. We hear that al-Bīrūnī himself had had a strong inclination to this matter from his youth. His teachers had solved the problem of the calculation of the sides of a spherical triangle from its angles, which later led al-Bīrūnī to devote a [26] special monograph to problems of spherical trigonometry. It is the extant *Kitāb Maqālīd ʿilm al-haiʾa.*[150] Here the discipline is still subordinate to astronomy. In the eighth chapter of his *al-Qānūn al-Masʿūdī*, al-Bīrūnī discussed the functions of tangent and cotangent and supplied the book with a tangent table.[151] Soon it occurred to him to use the new method also for the determination of longitudinal differences and distances between localities. The longitudinal differences calculated accordingly of numerous localities between Baghdad and Ghazna are congruent with modern values with deviations of only 6' to 45'. From his own report and lively descriptions, we learn about his method and its application to the long routes between Ghazna and Baghdad, where he conducted his work. He discussed his efforts on that matter in several works of which unfortunately only one survived. The interesting titles of those lost writings and the contents of the extant *Taḥdīd nihāyāt al-amākin* create the impression that al-Bīrūnī was indeed the one who promoted mathematical geography into an independent discipline,[152] whereby his surviving book deserves to be called the fundamental work on this subject.

At the beginning of the 5th/11th century, both al-Bīrūnī and Ibn al-Haiṯam independently came to the conclusion that the traditional method of determining the meridian line by means of the Indian circle was unsatisfactory due to errors caused by variations in the sun's declination. Ibn al-Haiṯam, unaware of the method proposed by al-Bīrūnī, found a way to determine the meridian by observing the corresponding altitudes of a fixed star and devised an instrument for this purpose (infra II, 146). Ibn al-Haiṯam's

[149] v. Willy Hartner, Matthias Schramm, *al-Bīrūnī and the Theory of the Solar Apogee: an example of originality in Arabic Science,* in: Scientific Change. Symposium on the History of Science. University of Oxford, 9-15 July 1961, ed. A. C. Crombie, London 1963, pp. 206-218; F. Sezgin, op. cit., vol. 6, p. 263.

[150] v. F. Sezgin, op. cit., vol. 6, pp. 266-267; edited and translated into French by Marie-Thérèse Debarnot, Damascus 1985.

[151] v. Carl Schoy, *Die trigonometrischen Lehren des persischen Astronomen Abu'l-Raiḥân Muḥ. ibn Aḥmad al-Bîrûnî dargestellt nach al-Qânûn al-Mas'ûdî*, Hanover 1927, pp. 46-57 (reprint in: Islamic Mathematics and Astronomy, vol. 35, pp. 161-278, esp. pp. 216-227); A. P. Juschkewitsch, op. cit., p. 302.

[152] F. Sezgin, op. cit., vol. 10, pp. 154-161.

method first appeared in Europe in the work of Regiomontanus of the first quarter of the 15th century.

The 5th/11th century also brought about great achievements in the field of mathematics. The works of al-Bīrūnī and Ibn al-Haiṯam alone show that substantial progress compared to the preceding century was already made in the first 30 or 40 years of the century.

Besides the above-mentioned advances towards infinitesimal calculus, al-Bīrūnī was able to enumerate in his *Qānūn*, the fundamental work of astronomy, twelve methods for trisecting an angle[153] worked out by his predecessors and contemporaries. These problems were solved through cubic equations and led also to attempts at solving the equations numerically. An interesting example for such an attempt was al-Bīrūnī's exercise to determine the sides of a nonagon.[154] Of his numerous further achievements in the field of mathematics known today, we shall mention only his mensuration of the circle through the sides of an inscribed and circumscribed nonagon, [27] which is actually a trigonometric problem; al-Bīrūnī reduces it to a cubic equation or (alternatively) solves it by means of a special iteration process (*istiqrā'*).[155]

Recent research has pointed out significant achievements by Ibn al-Haiṯam as well; some of these may be mentioned here. The famous mathematical-optical 'problema Alhazeni', which is named after him, occupies an important place in the history of mathematics. He posed that problem, i.e. "to determine the point of reflection of a spherical mirror from which the image of an object at a given place is reflected into an eye that is also at a given place"[156] and solved it himself with an equation of the fourth order. An important further development of the problem posed and solved by Ibn al-Haiṯam is reflected in the *Kitāb al-Istikmāl* by al-Mu'taman b. Yūsuf b. Aḥmad b. Sulaimān al-Hūdī, a ruler of Saragossa (d. 478/1085).[157] In his highly interesting book, which was rediscovered only two decades ago, al-Mu'taman introduces a simplification and generalization of Ibn al-Haiṯam's problem.[158] We shall show elsewhere that this problem and its solution, translated into Latin in the 12th century as part of the great optical work (*Kitāb al-Manāẓir*) by Ibn al-Haiṯam, occupied eminent mathematicians in Europe well into the 19th century (infra III, 187 f.).

Ibn al-Haiṯam is also one of the pioneers of infinitesimal calculus. Going beyond his predecessors Archimedes, Ṯābit b. Qurra, Ibrāhīm b. Sinān b. Ṯābit and Abū Sahl al-Kūhī, he also calculates paraboloids "which are produced by the rotation of the parabola around any arbitrary diameter of itself, and then especially those which are produced by the rotation of a part of the parabola around the ordinate."[159] His

[153] v. Carl Schoy, *Die trigonometrischen Lehren des … Abu'l-Raiḥân … al-Bîrûnî,* op. cit., pp. 23-30 (reprint in: Islamic Mathematics and Mathematics, vol. 35, pp. 193-200); A. P. Juschkewitsch, op. cit., pp. 301-302; F. Sezgin, op. cit., vol. 5, p. 376.

[154] v. Carl Schoy, *Die trigonometrischen Lehren des … Abu'l-Raiḥân … al-Bîrûnî,* op. cit., pp. 18-22 (reprint in: Islamic Mathematics and Mathematics, vol. 35, pp. 188-192); J. Tropfke, *Geschichte der Elementar-Mathematik, vol.* 3, 3rd ed., Berlin and Leipzig 1937, pp. 129-132; A. P. Juschkewitsch, op. cit., p. 258.

[155] v. Paul Luckey, *Der Lehrbrief über den Kreisumfang* (*ar-Risāla al-Muḥīṭīya*) von Ǧamšīd b. Mas'ūd al-Kāšī *übersetzt und erläutert,* ed. A. Siggel, Berlin 1953, pp. 46-47 (reprint in: Islamic Mathematics and Astronomy, vol. 56, pp. 227-329, esp. pp. 280-281); F. Sezgin, op. cit., vol. 5, p. 377.

[156] M. Cantor, op. cit., vol. 1, p. 789; F. Sezgin, op. cit., vol. 5, p. 359.

[157] v. Jan P. Hogendijk, *The geometrical parts of the Istikmāl of Yūsuf al-Mu'taman ibn Hūd (11th century),* in: Archives internationales d'histoire des sciences (Paris, Rome) 41/1991/207-281. It is noteworthy that Maimonides (Mūsā b. Maimūn) revised al-Mu'taman's book under the title *Tahḏīb al-Istikmāl* (see Ibn al-Qifṭī, *Ta'rīḫ al-hukamā',* Leipzig 1903, p. 319).

[158] v. Jan P. Hogendijk, *Al-Mu'taman's simplified lemmas for solving 'Alhazen's Problem',* in: *From Baghdad to Barcelona.* Studies in the Islamic exact sciences in honour of Prof. Juan Vernet, vol. 1, Barcelona 1996, pp. 59-101.

[159] v. H. Suter, *Die Abhandlung über die Ausmessung*

solution, "in which the sum of the fourth power occurs, contains a calculation which equals the computation of the definite integral $\int_0^a t^4\,dt$."[160]

One of the few achievements of Ibn al-Haiṯam in the field of geometry known so far assures him an outstanding position in the history of the discussion of Euclid's postulate of parallels (infra III, 126 f.). He attempts to prove the fifth postulate of the *Elements* according to the principle of motion, which leads to the assumption that lines of constant distance to a straight line must also be straight lines. Ibn al-Haiṯam "here takes a course which later many of his direct or indirect followers, including the geometers of the 18th century, pursued."[161]

[28] In trigonometry we may refer to his theorem on the spherical cotangent, which, interestingly enough, he derives purely geometrically and applies it in his treatise on the determination of the prayer direction (*qibla*)[162]. With this third main theorem of spherical trigonometry, Ibn al-Haiṯam proves to be a precursor of François Viète (1593).[163]

We shall not forget a contemporary of Ibn al-Haiṯam and al-Bīrūnī by the name of Muḥammad b. al-Laiṯ Abu l-Ǧūd.[164] We know a construction of his of a heptagon inside a circle, which he reduces to an equation of the third order.[165] About half a century earlier this construction had already been accomplished by Abū Sahl al-Kūhī[166] and Aḥmad b. Muḥammad as-Siǧzī,[167] but Abu l-Ǧūd took another path[168] and found the construction of the equation $x^3+13\tfrac{1}{2}x+5=10x^2$ which his predecessors did not succeed in finding.[169] In the construction of the heptagon the influence of the Arabic-Islamic culture area on European mathematicians is noticeable well into the 17th century.[170]

Abu l-Ǧūd was apparently the first mathematician who dedicated a treatise to forms of equations of the third order and methods for their solution. We learn this from his successor ʿUmar al-Ḫaiyām (2nd half of 5th/11th c.), who himself had not seen the work but had been informed about it by a contemporary.[171] The surviving work on algebra by ʿUmar al-Ḫaiyām (*al-Barāhīn ʿalā masāʾil al-ǧabr wa-l-muqābala*) was edited, studied and translated into French by Franz Woepcke 150 years ago and can be considered the true reflection of the development which algebra underwent in Arabic-Islamic mathematics. Al-Ḫaiyām enumerates twenty-five types of

des Paraboloids von el-Ḥasan b. el-Ḥasan b. el-Haitham, übersetzt und mit Kommentar versehen, in: Bibliotheca Mathematica (Leipzig) 3rd series, 12/1912/289-332, esp. p. 320 (reprint in: Islamic Mathematics and Astronomy, vol. 57, pp. 141-184, esp. p. 172); F. Sezgin, op. cit., vol. 5, p. 359.

[160] A. P. Juschkewitsch, op. cit., pp. 292-294; idem and B. A. Rosenfeld, *Die Mathematik der Länder des Ostens im Mittelalter,* Berlin 1963, pp. 155-156.

[161] A. P. Juschkewitsch, op. cit., p. 281; F. Sezgin, op. cit., vol. 5, pp. 49, 361.

[162] v. Carl Schoy, *Abhandlungen des al-Ḥasan ibn al-Ḥasan ibn al-Haiṯam (Alhazen) über die Bestimmung der Richtung der Qibla,* in: Zeitschrift der Deutschen Morgenländischen Gesellschaft (Leipzig) 75/1921/242-253 (reprint in: Islamic Mathematics and Astronomy, vol. 58, pp. 28-39); see F. Sezgin, op. cit., vol. 5, p. 362.

[163] v. J. Tropfke, *Geschichte der Elementar-Mathe-matik, vol.* 5, 2nd ed., Berlin and Leipzig 1923, p. 143.

[164] v. F. Sezgin, op. cit., vol. 5, pp. 353-355.

[165] ibid, vol. 5, p. 353.

[166] v. Yvonne [Dold-]Samplonius, *Die Konstruktion des regelmässigen Siebenecks nach Abû Sahl al-Qûhî Waiğan ibn Rustam,* in: Janus 50/1963/227-249; F. Sezgin, op. cit., vol. 5, p. 316.

[167] v. C. Schoy, *Graeco-arabische Studien…,* in: Isis (Brussels) 8/1926/21-40 (reprint in: Islamic Mathematics and Astronomy, vol. 62, pp. 29-48); F. Sezgin, op. cit., vol. 5, p. 330.

[168] v. C. Schoy, *Graeco-arabische Studien…*, op. cit, pp. 38-39 (reprint pp. 46-47); F. Sezgin, op. cit., vol. 5, pp. 353-354.

[169] v. A. P. Juschkewitsch, op. cit., p. 259.

[170] cf. J. Tropfke, Geschichte der Elementar-Mathematik, op. cit., vol. 3, p. 132.

[171] ʿUmar al-Ḫaiyām, *Risāla fi l-barāhīn ʿalā masāʾil al-ǧabr wa-l-muqābala*, hsg. in F. Woepcke, *L'algèbre d'Omar Alkhayyâmî,* Paris 1851, pp. (Arabic) 1 ff., esp. 47, tr. pp. 81-82 (reprint in: Islamic Mathematics and Astronomy, vol. 45, pp. 105-106, 158).

equations of which twelve are of linear or quadratic type; the rest consists of equations of the third order which can be solved by conic sections and are treated systematically by him. He complains that no algebraic solution of those equations had yet been found, but expresses his hopes that future generations might perhaps succeed in this.[172] Al-Ḫaiyām also points out that cubic equations which cannot be reduced to quadratic ones can generally not be solved with compass and ruler, i.e. through the properties of the circle. This view was later also expressed by René Descartes (1637) but was only proven by Pierre Laurent Wantzel (1837).[173]

The fact that the "excellent book" by ʿUmar al-Ḫaiyām had remained unknown "until the most recent times" and that mathematicians like Fermat (around 1637), [**29**] Descartes (1637), van Schooten (1659), E. Halley (1687) and others had "had to invent similar constructions over again" was regretted by the mathematician-historian Johannes Tropfke as late as 1937.[174]

Al-Ḫaiyām, who also counts among the great Persian poets and is a highly esteemed authority in other areas of science like astronomy and physics, found his own solution for the postulate of parallels. He rejects the use of motion as a means of proof in geometry, which Ibn al-Haiṯam had supported. His solution reappears in the 18th century in the work of the Italian mathematician Girolamo Saccheri (infra III, 127 f.). In the 5th/11th century we encounter several decisive achievements in the field of physics, including optics and meteorology.[175] Despite admirable individual studies by Eilhard Wiedemann and his disciples and despite the excellent work by Matthias Schramm, *Ibn al-Hayṯhams Weg zur Physik* (1963), the discipline of physics belongs to those areas of Arabic-Islamic science which still await a comprehensive treatment of however modest a scope. Approaching Ibn al-Haiṯam from his main work on optics (*Kitāb al-Manāẓir*) and his astrophysical writings, Schramm came to the conclusion that in these works Aristotelian physics, applied mathematics, traditional astronomy and optics are combined, and that this can be considered as typical of Ibn al-Haiṯam's scientific research.[176] On the other hand, he succeeded, according to Schramm, "in transforming Aristotelian metaphysics of nature, with the study of which he began his scientific endeavours, into a physical theory that provides a dynamic explanation of the kinematic model postulated by Ptolemy."[177] With his efforts in this respect, Ibn al-Haiṯam had "taken the first step that was to lead to one of the most remarkable achievements of the human mind as such, from the metaphysics of nature and its mathematical description towards physics, towards exact natural science based on mathematical methods."[178]

Ibn al-Haiṯam's continuously expanding physical-astronomical knowledge resulted in numerous monographs,[179] such as on the shape of the Earth, on burning mirrors, on rainbow and halo, on moonlight, on the light of the stars, on the anatomy of the visual organ and the nature of visual perception, on the "image of the eclipse" and on the lunar spots. He put down his knowledge of optical matters in the above-mentioned comprehensive work *Kitāb al-Manāẓir*. Like his Arabic predecessors Abū Bakr ar-Rāzī (d. 313/925), al-Fārābī (d. 339/950) and his contemporary Ibn Sīnā (d. 428/1037), and opposing Euclid and Ptolemy, he supported the Aristotelian view according to which visual perception does not involve rays emanating from the eye but rays emanating from the object. Mathematics and experiment always remain

[172] ʿUmar al-Ḫaiyām, op. cit., p. (Arabic) 6, tr. p. 9 (reprint op. cit., pp. 33, 199); F. Sezgin, op. cit., vol. 5, p. 50.
[173] v. J. Tropfke, op. cit., vol. 3, p. 125; A. P. Juschkewitsch, op. cit. p. 261.
[174] J. Tropfke, op. cit., vol. 3, p. 133.
[175] On this see F. Sezgin, op. cit., vol. 7, pp. 203-305.
[176] M. Schramm, *Ibn al-Haythams Weg zur Physik*, Wiesbaden 1963, p. 7.
[177] ibid, p. 143.
[178] ibid, p. 145.
[179] v. ibid, pp. 274-284.

in the foreground with all the problems he addressed, not only in the case of visual perception. According to Schramm's[180] opinion, the "Optics" display the mathematical genius of their author. For experimental purposes, Ibn al-Haiṯam constructed several instruments and devices, including a camera obscura.[181]

[30] In 1890 Leopold Schnaase[182] gave an excellent evaluation of Ibn al-Haiṯam's "Optics" and its significance, on the basis of its Latin translation. This evaluation was corroborated in a masterly way by Schramm's study. Referring to Ibn al-Haiṯam with the Latinized form of his name, Schnaase writes: "A comparison of Alhazen's achievements with those of Ptolemy shows what remarkable progress optics owe especially to the former; Alhazen was the first physicist to take into account the anatomy of the eye and to develop, on that basis, an elaborate theory of vision, a theory which—in spite of incorrect premises on the functions of the crystal lens—achieved results that almost agree with modern findings. The assumptions and experiments by which he determines the conditions of seeing single and double images must be regarded as his discoveries. Furthermore, he was the first to find definite proof that the theory of visual rays is incorrect, thus removing this theory once and for all from physics and establishing its opposite—a shift in the fundamentals of optics which was of far-reaching consequence. Even the claim that the transmission of light takes a certain time was already made by him. What a tremendous gap separates Ptolemy and Alhazen, the Greek and the Arabic school in this regard."

"In the theory of reflection, Alhazen eclipses all his predecessors by the clarity of his views. He is the first to prove, by means of an apparatus, the relevant laws for all kinds of mirrors at the same time and he is the first to give a correct explanation of mirror images. The investigations about the location and the distortions of the images as well as the solution of the problem named after him are all entirely novel."

"Alhazen surpasses Ptolemy also in the knowledge of refraction. He knows that the relation between the angles of refraction and incidence is not constant, that the path of light through two media backwards and forwards remains the same, and that the image of an object appears raised and magnified in a denser medium; finally he determines its location in a way still valid today. A particularly remarkable achievement of his experiments is the discovery of the magnifying power of spherical segments made of glass, a discovery that certainly had some influence on the early development of spectacle lenses.—The explanation of the apparent enlargement of stars at the horizon given by Alhazen is still the only one we know and much better than the one given by Ptolemy. The latter tries to explain the diminution at the zenith by the peculiar position of the eyes while looking up, whereas he excels Alhazen in other aspects of astronomical refraction.—It goes without saying that the calculation of the height of the atmosphere as well as experiments with a spherical burning-glass are not even hinted at by any physicist prior to Alhazen."

"… Even if views similar to his had occasionally been voiced earlier, to have clarified and to have decided finally between opposing views goes undoubtedly to Alhazen's credit; and thus he caused the magnificent shift in the fundamental theories of optics through which, at the beginning of the new millennium, new prospects were opened up for research and preparations were made for the dazzling discoveries of the modern age."

[180] M. Schramm, *Ibn al-Haythams Weg zur Physik*, Wiesbaden 1963, p. 14.

[181] Ibid., p. 210.

[182] Alhazen. *Ein Beitrag zur Geschichte der Physik*, in: Schriften der Naturforschenden Gesellschaft in Danzig, N. F. 7, Heft 7/1890,3/140-164, esp. pp. 163-164 (reprint in: Natural Sciences in Islam, vol. 33, pp. 26-52, esp. pp. 51-52).

[31] To this highly informative judgment by a physicist of humanistic persuasion from the end of the 19th century, I add the opinion of the contemporary historian of medicine, H. Schipperges,[183] which he formed by reading Matthias Schramm's study on the role of Ibn al-Haiṯam in the history of physics. He agrees with Schramm "that it was indeed Ibn al-Haiṯam who introduced for the first time a new methodic character into the natural sciences, a methodology which clearly distinguishes him from the Greek approach and which, passing beyond the epoch of Galileo, links up with modern experimental physics".

From the surviving works and also the titles of the lost treatises by Abu r-Raiḥān al-Bīrūnī we can appreciate the original and important contribution made to the physical science of this period. The maturity with which problems of natural sciences were approached during that period is reflected in the correspondence between al-Bīrūnī and Abū ʿAlī Ibn Sīnā, who was eleven years his junior, i.e. seventeen at the time. Besides the surviving texts of this correspondence,[184] Al-Bīrūnī's own statements on the question of the speed of light and global warming in his "Chronology of Eastern People" (*al-Āṯār al-bāqiya ʿan al-qurūn al-ḫāliya*),[185] where he refers to this correspondence and speaks of Ibn Sīnā as a young man of merit, are vivid illustrations of the elevated scientific spirit of that period. An assessment of al-Bīrūnī's status in the history of physics is still awaited. So far, mainly his achievement in determining the weights of objects having the same volume has been studied and evaluated from the perspective of the history of science.[186] After several failed experimental setups, he finally succeeded in constructing a device for this purpose which resembles the modern pharmacy-pycnometer (infra V, 9 ff.). The specific gravities of various metals and precious stones as determined by him and his successors with this device are almost identical to their modern values. Mention should also be made of the interesting attempt to determine the height of the atmosphere in the second half of the 5th/11th century. The problem was solved by trigonometric-astronomical methods; this solution can be found in the Latin translation *De crepusculis et nubium ascensionibus*, which was erroneously attributed to Ibn al-Haiṯam. The real author[187] was the Andalusian scholar Abū ʿAbdallāh Muḥammad Ibn Muʿāḏ al-Ǧaiyānī.[188] This Latin treatise, printed in Portugal in 1542, had a lasting impact on the Occident.[189]

[32] The two major works by Abū ʿAlī Ibn Sīnā (d. 428/1037), his "Canon of Medicine" (*al-Qānūn fi ṭ-ṭibb*) and the encyclopaedia of philosophical and exact sciences entitled "Book of Healing [of the Soul]" (*Kitāb aš-Šifāʾ*), be-

[183] Review of Schramm's book in: Archives internationales d'histoire des sciences (Paris) 17/1964/183-184, esp. p. 184.

[184] Edited with Turkish translation by Muhammad Tancî in: *Beyrunî'ye armağan*, (on the occasion of al-Bīrūnī's 1000th anniversary), ed. by Aydın Sayılı, Ankara 1974, pp. 231-301.

[185] Ed. Eduard Sachau, Leipzig 1878 (reprint in: Islamic Mathematics and Astronomy, vol. 30), pp. 256-257; idem, English transl., London 1879 (reprint in: Islamic Mathematics and Astronomy, vol. 31), p. 247.

[186] E. Wiedemann, *Über das al Bêrûnîsche Gefäß zur spezifischen Gewichtsbestimmung*, in: Verhandlungen der Deutschen Physikalischen Gesellschaft im Jahre 1908, Braunschweig 1908, pp. 339-343 (reprint in: Natural Sciences in Islam, vol. 46, pp. 113-117); idem, *Über die Verbreitung der Bestimmungen des spezifischen Gewichtes nach Bîrûnî*, in: Sitzungsberichte der Physikalisch-medizinischen Sozietät (Erlangen) 45/1913/31-34 (reprint in: Natural Sciences in Islam, vol. 46, pp. 119-122); Heinrich Bauerreiss, *Zur Geschichte des spezifischen Gewichtes im Altertum und Mittelalter*, Ph. D. Thesis Erlangen 1914, p. 28 ff. (reprint in: Natural Sciences in Islam, vol. 45, pp. 193-324, esp. pp. 224 ff.).

[187] v. A. I. Sabra, *The authorship of the Liber de crepusculis, an eleventh-century work on atmospheric refraction*, in: Isis (Berkeley) 58/1967/77-85.

[188] v. F. Sezgin, op cit., vol. 5, p. 109.

[189] v. Matthias Schramm, *Ibn al-Haythams Stellung in der Geschichte der Wissenschaften*, in: Fikrun wa Fann (Hamburg) 3/1966,6/65-85, esp. pp. 73-74; F. Sezgin, op. cit., vol. 5, p. 364.

long indisputably to the most important scientific achievements of the Arabic-Islamic culture area.

Julius Hirschberg[190] described the "Canon" by this extraordinarily talented and diligent thinker as "distinguished by order and exactitude, a very extensive and comprehensive didactic system covering the entire science of medicine including surgery—almost without parallel in world literature." He goes on to add: "From the Greeks we have inherited only collections, extracts, compilations. The Canon is a work as of one mold. Nowadays a complete medical staff is required to produce a 'manual' like this. For half a millennium, the Canon remained effective and Ibn Sīnā reigned supreme, like Aristotle and Galen." The Canon was translated into Latin in the 12th century and influenced medical science in the West up to the 17th century.

The second, equally extensive, encyclopaedic work by Ibn Sīnā deals with the theory of the principles of the natural bodies and the cosmos, origin and end, potency and suffering in nature; it covers meteorology and geology, psychology, botany and zoology, mathematics and astronomy, music, philosophy and logic.[191] The book was translated into Latin by John Hispaniensis in the 12th century and influenced the development of sciences in the Occident for centuries.

In the context of Ibn Sīnā's two works we should also mention the great achievements of the Christian ophthalmologist ʿAlī b. ʿĪsā al-Kaḥḥāl (1st half of the 5th/11th c.). J. Hirschberg considers his work as leading amongst the textbooks of ophthalmology produced for the next 800 years. About its Latin translation, however, he wrote: "Ophthalmology in the Occident would have reached a higher standard and could have contributed more to the benefit of humanity had the early Latin translation of his work been more reliable and consequently in wider circulation."[192] Hirschberg points out that operations under anaesthesia belonged to the common medical procedures and regrets that surgically induced "sleep" (*tanwīm*) practised by the Arabs remained completely unknown to the historians of medicine.[193]

From the geographical works of this century the first comprehensive geographical lexicon known to us should be mentioned. It was compiled by Abū ʿUbaid ʿAbdallāh b. ʿAbdalʿazīz al-Bakrī[194] of Cordova (d. 487/1094). This geographer, historian and lexicographer compiled an alphabetically arranged reference book on the basis of numerous monographs and other available sources about caravanserais, mountains, rivers, wells, etc. The same author left behind a valuable topographic geography (*Kitāb al-Masālik wa-l-mamālik*), independent of the eastern school of anthropogeography. Its high value lies in its excellent description of Spain and [33] rare information on Central and Eastern Europe and North Africa, taken from sources otherwise lost.[195]

In the field of historiography we shall mention al-Bīrūnī's book on India, which bears witness to its author's exemplary veracity, critical mind, keen observation and a remarkable cosmopolitan openness and objectivity. Al-Bīrūnī deals with the culture, religions and sciences of the Indians on the basis of his own research and observations made over many years while living

[190] *Geschichte der Augenheilkunde, vol. 2: Geschichte der Augenheilkunde im Mittelalter,* Leipzig 1908 (= Graefe-Saemisch, *Handbuch der gesamten Augenheilkunde, vol.* 13), p. 16.

[191] *Die Metaphysik Avicennas,* übersetzt und erläutert von Max Horten, Halle and New York 1907 (reprint: Islamic Philosophy, vol. 40-41), p. VIII.

[192] *Ali ibn Isa. Erinnerungsbuch für Augenärzte,* übersetzt und erläutert von J. Hirschberg und J. Lippert, Leipzig 1904 (reprint: Islamic Medicine, vol. 44), p. XXXVII.

[193] ibid, p. XXXVI; F. Sezgin, op. cit., vol. 3, p. 338.

[194] *Muʿǧam ma staʿǧam min asmāʾ al-bilād wa-l-mawāḍiʿ, ed. Muṣṭafā as-Saqqā,* 4 vols., Cairo 1945-1951.

[195] This part bears the title *Kitāb al-Muġrib fī ḏikr bilād Ifrīqīya wa-l-Maġrib*, ed. by William Mac Guckin de Slane, Algiers 1857 (reprint: Islamic Geography, vol. 134), French translation ibid, Algiers 1913 (reprint: Islamic Geography, vol. 135).

in India. In the introduction, he states:[196] "This is not a polemical book but a plain factual report. I shall describe the theories of the Hindus as they are and in that connection mention similar theories of the Greeks in order to demonstrate the relationship between the two." Al-Bīrūnī's book appears to stand in the tradition of the spirit we already encounter in the early Abbasid period (supra, p. 23) and which aims at getting to know foreign cultures and religions, a spirit that found expression in many travelogues, in the masterworks of al-Masʿūdī (supra, p. 23), and in al-Bīrūnī's "Chronology of Eastern People". Al-Bīrūnī's book on India marks an apex that—perhaps not only in Arabic-Islamic culture—could not be surpassed.

In conclusion of this selection of outstanding achievements of the 5th/11th century we shall mention the two extremely important works by ʿAbdalqāhir b. ʿAbdarraḥmān al-Ǧurǧānī (d. 471/1078) from the field of linguistics. These are his *Kitāb Dalāʾil al-iʿǧāz* and the *Kitāb Asrār al-balāġa*. In an excellent study of the former work, Max Weisweiler[197] pointed out that its author attempts "to understand linguistic phenomena psychologically according to their cause, purpose and effect." Al-Ǧurǧānī does not seem to have been aware that with his conceptions and examples he had created a stylistic grammar. In the next generation it already turned into a new branch of linguistics in the form of a systematically arranged textbook entitled *ʿilm al-maʿānī*.[198] That al-Ǧurǧānī's admirable ideas could not appear all of a sudden, but represent an already high standard achieved in the course of a long-term upward development requires, it is hoped, no further explanation. The achievements preceding al-Ǧurǧānī are also quite well known today.[199]

While editing and translating ʿAbdalqāhir b. ʿAbdarraḥmān al-Ǧurǧānī's second book entitled *Asrār al-balāġa* ("The Secrets of Style"), Hellmut Ritter[200] discovered "a psychological foundation of aesthetic judgments on poetry." This scholar, who spent some twenty-five years editing the book and translating it into German and who was undoubtedly one of the greatest connoisseurs of Arabic language and literature, stressed the fact that to his knowledge something like that had "never before been attempted on Islamic [34] ground."[201] At any rate, al-Ǧurǧānī in retrospect turns out a precursor of *ʿilm al-bayān* which expanded, three to four generations later, into an independent branch of linguistics.

The 6th/12th Century

Returning to astronomy, we see that Ibrāhīm b. Yaḥyā az-Zarqālī, active around the turn of the 5th/11th to the 6th/12th century in Muslim Spain, achieved a significantly more exact measurement of the proper motion of the Sun's apogee than his predecessors. He arrived at a value of 1° in 299 years for this motion, i.e. 12.09" in one year, which approaches the current value of 11.46" very closely.[202] This value and knowledge of the model developed in this connection by az-Zarqālī reached Copernicus via two compilations, *Theoricæ planetarum* by Georg Peurbach and *Epitome* by Johannes

[196] *Kitāb Taḥqīq mā li-l-Hind min maqūla maqbūla fi l-ʿaql au marḏūla*, ed. by Edward Sachau, London 1887 (reprint Islamic Geography, vol. 105); translation of the quotation based on Max Krause, *al-Biruni. Ein iranischer Forscher des Mittelalters,* in: Der Islam (Berlin) 26/1942/1-15, esp. p. 13 reprint Islamic Mathematics and Astronomy, vol. 36. pp. 1-15).

[197] *ʿAbdalqāhir al-Curcānī*'s *Werk über die Unnachahmlichkeit des Korans und seine syntaktisch-stilistischen Lehren*, in: Oriens 11/1958/77-121, esp. p. 79.

[198] cf. Udo Gerald Simon, *Mittelalterliche arabische Sprachbetrachtung zwischen Grammatik und Rhetorik: ʿilm al-maʿānī bei as-Sakkākī*, Heidelberg 1993, pp. 3-4.

[199] v. F. Sezgin, op. cit., vol. 9, p. 11.

[200] *Die Geheimnisse der Wortkunst* (*Asrār al-balāġa*) des ʿAbdalqāhir al-Curcānī. Translated from the Arabic, Wiesbaden 1959, p. 1.

[201] H. Ritter, op. cit., p. 1..

[202] v. G. J. Toomer, *The solar theory of al-Zarqāl. A history of errors*, in: Centaurus (Copenhagen) 14/1969/306-336; F. Sezgin, op. cit., vol. 6, pp. 27, 43.

Regiomontanus.[203] By means of comparison it has already been established that the tables used by az-Zarqālī while formulating his solar theory and the corresponding tables found in *De revolutionibus* by Copernicus show general agreement in arrangement and organisation, leaving aside one minor deviation.[204] Johannes Kepler also learned of az-Zarqālī's observations for determining the Sun's apogee.[205] Furthermore, it is assumed that there might be a connection between Kepler's concept of the Mars-orbit as an oval and az-Zarqālī's oval orbit of Mercury.[206]

A groundbreaking invention in the history of the astrolabe also bears az-Zarqālī's name. He replaced polar stereographic projection with horizontal projection, whereby the main body of the instrument was reduced to one single plate rather than appending separate plates for various geographical latitudes. This instrument, known in astronomical literature as saphæa or universal disc, later enjoyed wide circulation in Europe (infra II, 116 ff.).

Another astronomical instrument that appeared in the 6th/12th century found wide dissemination in Europe under the name torquetum. It was developed by the Andalusian astronomer Ǧābir b. Aflaḥ (infra II, 154). He described the instrument in his work on the revision of the *Almagest* in which he criticises Ptolemy sharply. It is well-known that this criticism of the *Almagest*[207], which was translated into Latin by Gerard of Cremona, a contemporary of the author, exerted considerable influence both on the subject itself and on mathematics (infra II, 12).

The linear astrolabe of Šarafaddīn al-Muẓaffar b. Muḥammad b. al-Muẓaffar aṭ-Ṭūsī (d. after 606/1209) is yet another astronomical instrument invented at this time. In this instrument, called *ʿaṣā aṭ-Ṭūsī* ("aṭ-Ṭūsī's staff") after its inventor, the projection of a planispheric astrolabe is transcribed on a straight line drawn on a staff (infra II, 134 ff.).

Meanwhile in theoretical astronomy, strong opposition against the Ptolemaic system of celestial motions arose in the 6th/12th century in Muslim Andalusia. The exponents of this criticism were mostly philosophers, namely Muḥammad b.Yaḥyā Ibn Bāǧǧa (d. 533/1139), Muḥammad b. ʿAbdalmalik Ibn Ṭufail [35] (d.581/1185), Muḥammad b. Aḥmad Ibn Rušd (d. 595/1198) and Ibn Ṭufail's pupil, Nūraddīn al-Biṭrūǧī (ca. 600/1200). They found the principle of uniformity in planetary motions disturbed by the concept of eccentricity and epicycles and attempted to restore this basic principle by means of new models. The book of the last representative of this school of thought, Nūraddīn al-Biṭrūǧī, exercised a great and lasting influence on western astronomy. Shortly after the book had first appeared it already reached European countries beyond Spain in translation by Michael Scotus (d. ca. 1235). Like Ibn Ṭufail and Ibn Rušd, al-Biṭrūǧī was convinced that the planetary orbits must run concentrically around the centre of the Earth and, like Ibn Rušd, he believed that they follow a spiral path around various axes (infra II, 12f.).[208]

In the eastern part of the Islamic world, the above-mentioned Šarafaddīn aṭ-Ṭūsī (d. after 606/1209) played a pivotal role in the mathematics of this epoch. With his book entitled *al-Muʿādalāt,*[209] he had an important part in the process of the systematic treatment of equations of the third order. He pursued ʿUmar al-Ḫaiyām's path, and his book gives an idea of the progress achieved in the mathematics of the Islamic world during the preceding century. This progress is apparent primarily in the fusion of arithmetical and geometrical traditions and the

[203] v. F. Sezgin, op. cit., vol. 6, p. 43.
[204] v. ibid, vol. 6, p. 43.
[205] v. ibid, vol. 6, pp. 43-44.
[206] v. ibid, vol. 6, p. 44.
[207] v. ibid, vol. 6, pp.45, 93.

[208] v. F. Sezgin, op. cit., vol. 6, pp. 36-37
[209] *Sharaf al-Dīn al-Ṭūsī, oeuvres mathématiques: Algèbre et géométrie au XII e siècle*. Texte établi et traduit par Roshdi Rashed, 2 vols., Paris 1986.

formulation and proof of a number of algebraic processes.[210]

From the western part of the Islamic world, I would like to mention once more the name of the Andalusian mathematician and astronomer Ǧābir b. Aflaḥ. Many historians of mathematics are of the opinion that the trigonometric chapter of his critical review of the *Almagest* exerted considerable influence on this discipline in the West. Thus Regiomontanus (1436-1476) in his *De triangulis omnimodis* is said to have used material from Ǧābir b. Aflaḥ's book. Whereas in the first books of this work, to quote Johannes Tropfke,[211] "he independently revised the results of his predecessors, in the fourth book he adopted Ǧābir's proofs almost verbatim." In the history of spherical trigonometry[212] one basic formula is called "Geber's theorem" after him. It states that a right-angled spherical triangle can be calculated from a given side α and a given adjacent angle β, which leads to the formula $\cos \alpha = \cos \alpha \sin \beta$.

Concluding the description of mathematics of the 6th/12th century, a mathematician of the first order, Aḥmad b. Muḥammad Ibn as-Sarī b. aṣ-Ṣalāḥ (d. 548/1153), shall be mentioned. He wrote a number of discourses devoted to the verification and criticism of the results of Greek and earlier Arab authorities. From a study by Matthias Schramm on one of those discourses, we learn that Ibn aṣ-Ṣalāḥ was actually qualified for such a criticism and that his aim was historical justice; for instance, when reviewing the criticism of his Arab predecessors on the Greeks, he sometimes refutes the former.[213]

[36] From the field of physics and technology we know at the present time at least two important works which document the high standard of those disciplines in the 6th/12th century in the Arabic-Islamic culture area. They are *Mīzān al-ḥikma* by ʿAbdarraḥmān al-Ḫāzinī[214] (written 515/1121) and *al-Ǧāmiʿ bain al-ʿilm wa-l-ʿamal fī ṣināʿat al-ḥiyal* by Abu l-ʿIzz Ismāʿīl Ibn ar-Razzāz al-Ǧazarī[215] (written around 600/1203).

The title *Mīzān al-ḥikma* promises a book about the "balance of wisdom", but the content of the book goes far beyond that. Above all, the author extends and supplements al-Bīrūnī's results on the determination of specific gravities. The balance mentioned in the title is constructed in such a way that it can achieve a precision of 1/60000 (infra V, 5f). Al-Ḫāzinī has a clear notion of the dependence of the specific gravity of water on temperature and interprets in this sense his observation that water put on his balance had a lower weight in summer than in winter. He also describes a special clepsydra built on

[210] J. L. Berggren, *Innovation and tradition in Sharaf al-Dīn al-Ṭūsīʿs al-Muʿādalāt*, in: Journal of the American Oriental Society (Ann Arbor, Mich.) 110/1990/304-309, esp. p. 309.

[211] *Geschichte der Elementar-Mathematik*, 2nd ed., vol. 5, p. 137; F. Sezgin, op. cit., vol. 5, p. 53.

[212] A. von Braunmühl, *Vorlesungen über Geschichte der Trigonometrie*, vol.1, Leipzig 1900, pp. 81-82; J. Tropfke, op. cit., vol. 5, pp. 131-132; A. P. Juschkewitsch, op. cit., p. 304; F. Sezgin, op. cit., vol. 5, p. 53.

[213] *Ibn al-Haythams Stellung in der Geschichte der Wissenschaften*, in: Fikrun wa Fann (Hamburg) 3/1966,6/65-85, esp. p. 81.

[214] v. Nicolas Khanikoff, *Analysis and extracts of Kitāb Mīzān al-ḥikma (Arabic in the original) "Book of the Balance of Wisdom", an Arabic work on the water-balance, written by Khâzinî, in the twelfth century*, in: Journal of the American Oriental Society (New Haven) 6/1860/1-128 (reprint in: Natural Sciences in Islam, vol. 47, pp. 1-128; Thomas Ibel, *Die Wage im Altertum und Mittelalter*, Erlangen 1908, pp.73-162 (reprint in: Natural Sciences in Islam, vol. 45, pp. 77-166); C. Brockelmann, *Geschichte der arabischen Litteratur*, 1st suppl. vol., p. 902. The text was published in Hyderabad in 1940 from a manuscript kept in a mosque in Bombay (reprint in: Natural Sciences in Islam, vol. 47, pp. 219-510).

[215] The work, preserved in several manuscripts, was edited by Aḥmad Y. al-Ḥasan, Aleppo 1979; Engl. transl. Donald Hill, *The Book of Knowledge of Ingenious Mechanical Devices*, Dordrecht and Boston 1974; facsimile edition of the manuscript, Ayasofya 3606, by Institut für Geschichte der Arabisch-Islamischen Wissenschaften 2002.

the principle of a balance with which minutes were measured (infra III, 117), and also an areometer, which had already been known in late antiquity (infra V, 12 ff.), for the determination of the specific gravity of liquids.

Of great interest is al-Ḫāzinī's knowledge that a body gains weight in thinner air and loses weight in denser air or when submerged in water.[216] The following idea of his is also remarkable: "Liquids occupy a larger volume in a container when the latter is closer to the centre of the Earth and a smaller volume when the container is farther removed from it."[217] In 1890 E. Wiedemann found the same idea in Roger Bacon's *Opus majus*[218] and observed that the proofs of both authors are related, even if Bacon's reasoning is "somewhat more laboured than the Arab's".

Al-Ḫāzinī's *Mīzān al-ḥikma* is a book of physics in the strict sense of the word; it imparts to us a wealth of physical laws known to Arabic-Islamic scholars in the 6th/12th century. The high quality of the description of the experiments reminiscent of Ibn al-Haiṯam's and al-Bīrūnī's time is remarkable, and also the fact that he uses the experiment as a systematic means for research.

[37] The second of the books mentioned was written by the otherwise unknown Ibn ar-Razzāz al-Ǧazarī upon commission by the local ruler of Āmid Nāṣiraddīn Maḥmūd b. Muḥammad b. Qarā'arslān (r. 597/1200-619/1222), and was completed two years after the latter's accession to power. Several manuscripts of the book with illustrations in colour have come down to us. It is without doubt the most beautiful of the extant works in the field of mechanics. The author mentions amongst the contents of his book "water driven machines for equinoctial and temporal hours" and devices used for "moving bodies from their natural position by means of [other] bodies". He describes fifty machines and devices in all clarity from the point of view of an engineer and provides them with fifty complete and about a hundred partial drawings of such quality that one can reconstruct the machines without any substantial problems.

This book, originating in the eastern part of Asia Minor under the adverse political conditions of those times when the war against the crusaders impeded communication amongst the people and the exchange of books and knowledge between the countries of the Islamic world, probably does not reflect the state-of-the-art reached by Arabic-Islamic technology at that time or even in general. It is a book compiled by a capable engineer according to his talents and his understanding on the basis of his knowledge of the sources and within the bounds of the conditions of his environment. For instance, when the conical valve for regulating the water level in hydraulic devices appears for the first time in al-Ǧazarī's book, this is no sufficient reason to consider him its inventor.[219] Incidentally, this type of valve was not known in Europe until the 18th century. Whether it reached the West from the Arabic-Islamic area or whether it developed

[216] v. *Mīzān al-ḥikma*, ed. Khanikoff, p. 68 (reprint p. 68); ed. Hyderabad p. 69 (reprint p. 414); E. Gerland, *Geschichte der Physik. Erste Abteilung: Von den ältesten Zeiten bis zum Ausgange des achtzehnten Jahrhunderts*, Munich and Berlin 1913 (= Geschichte der Wissenschaften in Deutschland. Neuere Zeit., vol. 24) p. 175.

[217] *Mīzān al-ḥikma*, ed. Khanikoff, p. 38 (reprint p. 38); ed. Hyderabad, p. 25 (reprint p. 484); E. Wiedemann, *Inhalt eines Gefäßes in verschiedenen Abständen vom Erdmittelpunkte nach Al Khâzinî und Roger Baco*, in: Annalen der Physik (Leipzig) 39/1890/319 (reprint in: Gesammelte Schriften, vol. 1, p. 41); idem, *Inhalt eines Gefäßes in verschiedenen Abständen vom Erdmittelpunkt*, in: Zeitschrift für Physik (Braunschweig and Berlin) 13/1923/59-60 (reprint in: Natural Sciences in Islam, vol. 47, pp. 217-218).

[218] *The 'Opus majus' of Roger Bacon*, ed. John H. Bridges, London 1900 (reprint Frankfurt 1964), vol. 1, pp. 157-159; Engl. transl. Robert B. Burke, Philadelphia 1928, vol. 1, pp. 179-180

[219] v. the introduction to our facsimile edition, p. VIII.

again independently remains a matter of speculation.[220]

As far as al-Ǧazarī's own creative contribution to his book is concerned, we can only assume—as long as the research in the history of technology in Arabic-Islamic culture does not yet stand on firm ground and its position in the universal history of science has not yet been sufficiently cleared up—that some of the inventions described in his book are his own.[221] At any rate, it is an historic document of high cultural and scientific standards, so much can be said with certainty. It provides unique material on technical instruments and devices, about their construction and the materials used. Thus the book contributes fundamentally to the understanding of the general history of technology, although it is possibly not representative of the standard attained in the Islamic world in general. Some of the machines described show affinity to such which later appear in European books on mechanical devices and automata, even though there does not seem to be a direct connection.

The most important achievement of the 6th/12th century in the field of geography is the work by Abū ʿAbdallāh Muḥammad b. Muḥammad b. ʿAbdallāh al-Idrīsī, a descendant of Idrīs II who ruled in Malaga during the years 1042-47 and 1054-55 CE. This nobleman from the western part of the Islamic world came to Palermo either as a traveller or as a guest of the Norman king Roger II (r. 1130-1154). There he prepared, during his stay of many years, upon commission by his host, a circular world map on [38] a silver disc, 70 regional maps and a book entitled *Nuzhat al-muštāq fi ḫtirāq al-āfāq* on the geography of the world. For the succeeding king, Guillaume I (r. 1154-1166) he abridged his book under the title *Uns al-muhaǧ wa-rauḍ al-faraǧ* with 72 regional maps. In the year 1160 CE., the circular silver world map (Tabula Rogeriana) was smashed to pieces by rebels and divided amongst themselves.

The world map and some of the sectional maps survive as the final product of multiple copying in a number of manuscripts of the geographical work. The question of how al-Idrīsī was able to create these maps, and the question of the importance of the entire work for the history of geography, were discussed for a long time and found widely differing answers. In the discussion of the map it was almost always assumed that al-Idrīsī must have used the Ptolemaic world map as his model. The world map and several regional maps by the geographers of Caliph al-Maʾmūn (r. 198/813-218/833) could of course not be taken into account, as they were rediscovered only about twenty years ago. While referring to the detailed discussion of this question in volumes 10 and 11 of my *Geschichte des arabischen Schrifttums* and to the yet unpublished manuscript of the volume on anthropogeography, I will state my view very briefly here: The Ptolemaic Geography itself actually consists of an instruction for drawing maps and as such most probably did not include any maps. The maps attributed to Ptolemy were reconstructed around the turn of the 13th to the 14th century CE by the Byzantine Maximos Planudes on the basis of the coordinates from Ptolemy's book and probably by consulting the world map of the Maʾmūn geographers.[222] Today we have evidence that al-Idrīsī used the Maʾmūn map as his model. Leaving aside certain obvious errors and deviations, such as the omission of the graticule which was erroneously replaced by lines of equal distance meant to represent the seven climates, the Idrīsī map surpasses its model in various respects. Thus Europe, in particular the Mediterranean area, is represented more accurately, North-East Asia has been completely revised, and Central Asia with its systems of

[220] v. Otto Mayr, *The Origins of Feedback Control*, in: The Scientific American (New York) 223/1970/111-118, esp. 114; D. R. Hill, *The Book of Knowledge of Ingenious Mechanical Devices*, op. cit., p. 279.

[221] v. the introduction to our facsimile edition, p. VIII-IX.

[222] v. F. Sezgin, op. cit., vol. 10, pp. 50 - 57.

lakes and rivers also has been developed further. Hence the question arises how a geographer in Sicily in those days could have accomplished this cartographic survey, which in fact required work to be carried out locally and for generations. In fact, I believe that the results of such work reached al-Idrīsī in the form of a book supplied with maps. The work written by one Ḫānāḫ (Ġāġān or Ǧānāḫ) b. Ḫāqān al-Kīmākī is mentioned by al-Idrīsī[223] amongst his sources. Apparently, this geographical-cartographical work by a prince of the Kimak-Turks was based on a long-term collection of data, gathered locally in the tradition of Arabic-Islamic cartography. The shape of North and North-East Asia in al-Idrīsī's map, which is completely new compared with the map of the Maʾmūn geographers—not to mention the so-called Ptolemaic maps—appears in most western world maps until the 18th century. As far as I am aware, no historian of geography has as yet asked himself from where this depiction of Asia in those Western maps originated.

In my opinion, al-Idrīsī's world map, despite its shortcomings, allows us to trace the development of cartography since the appearance of the Maʾmūnian map in the Arabic-Islamic culture area [39] and, furthermore, it helps us find an answer to the old question concerning the origin of the so-called portolan-maps and their "sudden emergence" amongst European navigators and cartographers at the turn of the 13th to the 14th century.

However, this high estimation of al-Idrīsī's world map from the viewpoint of the history of cartography presupposes the clarification of one fact. The circular world map which survived in several manuscripts of his *Geography* and which had suffered from repeated copying was known only to a few arabists prior to the appearance of the commendable work *Mappae arabicae*[224] (1926-1931) by Konrad Miller. In his book Miller published the surviving copies of the circular world map, the sectional maps and a world map reconstructed by him after the sectional maps. In spite of al-Idrīsī referring to his world map as being circular and although its copies as preserved in various manuscripts are, indeed, all circular, Miller was convinced that the world map must have been rectangular (infra III, 28) and consequently felt justified in reconstructing the missing original by patching together the seventy rectangular sectional maps. The orthogonal world map thus reconstructed found wide distribution, even though not only is the north depicted as wide as the regions of the equator, which distorts the cartographic image, but also the configuration of northern Asia and Africa is obscured completely. Only a few people would be aware that this map was reconstructed by Miller using al-Idrīsī's sectional maps, while the world map found in al-Idrīsī's book itself is circular and substantially different from the one in circulation. With the aid of electronic data-processing, we have attempted to graduate the sectional maps orthogonally and to transform them into a stereographic projection, occasionally making reference to the extant circular world map. We believe that the resulting map gives a better idea of al-Idrīsī's intentions and hence published it as a poster.

As regards the text of al-Idrīsī's book, we can say that through his Arabic sources we gain much information about the geography of European countries. The parts concerning Sicily, Italy, France, Germany, the Scandinavian and Slavonic countries and the Balkans have consequently been made the subject of detailed studies by arabists.[225]

[223] *Nuzhat al-muštāq*, in: *al-Idrīsī. Opus geographicum*, ed. A. Bombaci et al., Naples and Rome 1970-1984, vol. 1, p. 5; F. Sezgin, op. cit., vol. 10, p. 349.

[224] *Mappae arabicae. Arabische Welt- und Länderkarten des 9. - 13. Jahrhunderts in arabischer Urschrift, lateinischer Transkription und Übertragung in neuzeitliche Kartenskizzen.* Edited with introduction by Konrad Miller. 6 volumes. Stuttgart 1926-1931 (reprint: Islamic Geography, vols. 240-241).

[225] Most of these studies were collected at the Institut

Meanwhile, in the field of philosophy a new school of thought developed, known as *falsafat al-išrāq*. Its founder was Šihābaddīn Yaḥyā b. Ḥabaš as-Suhrawardī (d. 578/1191). The basis of his new philosophical system was a metaphysic of light. "Being and non-being, substance and accidence, cause and result, thought and feeling, soul and body, he explains all through his doctrine of *Ishrāḳ*; he regards everything that lives or moves or exists as light and even his proof for the existence of God is based on this symbol."[226]

In the area of philology an increasing interest in terminologies and foreign languages, and in the investigation of foreign elements in Arabic, is apparent in this century—a trend not without precursors in the preceding centuries. As an example we may refer to the botany by the above-mentioned al-Idrīsī, his al-*Ǧāmiʿ li-ṣifāt aštāt* [40] *an-nabāt wa-ḍurūb anwāʿ al-mufradāt.*[227] For the more than 1200 drugs mentioned, [228] he compiled "thousands of synonyms from about a dozen languages."[229] Abū Manṣūr Mauhūb b. Aḥmad al-Ǧawālīqī, a philologist from Baghdad[230] (d. 539/1144) devoted one of his books to foreign and loan words in Arabic (*Kitāb al-Muʿarrab*). In a relatively extensive Arabic-Persian dictionary entitled *aṣ-Ṣaḥīfa al-ʿaḏrāʾ*,[231] which has so far remained quite unknown, one Muḥammad b. ʿUmar an-Nasafī[232] (6th/12th c.) compiled material from the related works of two predecessors, the *Kitāb al-Maṣādir* by al-Ḥusain b. ʿAlī az-Zauzanī[233] (d. 486/1093) and the *Kitāb as-Sāmī fi l-asāmī* as well as *al-Hādī li-š-šādī* by Aḥmad b. Muḥammmad b. Aḥmad al-Maidānī[234] (d. 518/1124).[235]

Finally the progress made during the 6th/12th century in the field of military technology shall be mentioned. A book brought to the attention of the interested public in 1948 by Claude Cahen yields valuable information on this matter, rendering various theories and assumptions by historians of this subject obsolete. This book, entitled *Tabṣirat arbāb al-albāb*, was written under the Ayyubid Sultan Ṣalāḥaddīn (Saladin, r. 569/1174-589/1193), by Murḍā b. ʿAlī b. Murḍā aṭ-Ṭarsūsī (infra V, 94 passim). Amongst other

für Geschichte der Arabisch-Islamischen Wissenschaften in Frankfurt and reprinted as: Islamic Geography, vols. 2-8.

[226] v. van den Bergh, *as-Suhrawardī*, in: Enzyklopädie des Islām, vol. 4, Leiden and Leipzig 1934, pp. 547-548.

[227] Facsimile edition, Frankfurt, Institut für Geschichte der Arabisch-Islamischen Wissenschaften, 3 vols, 1995.

[228] Max Meyerhof, *Über die Pharmakologie und Botanik des arabischen Geographen Edrisi,* in: Archiv für Geschichte der Mathematik, der Naturwissenschaften und der Technik (Leipzig) 12/1930/45-53, 236, esp. p. 51 (reprint in: Islamic Medicine, vol. 96, pp. 59-68, esp. p.65); idem, *Die allgemeine Botanik und Pharmakologie des Edrisi*, in: Archiv für Geschichte der Mathematik, der Naturwissenschaften und der Technik (Leipzig) 12/1930/225-236, esp. p. 226 (reprint in: Islamic Medicine, vol. 96, pp. 69-80, esp. p. 70).

[229] al-Idrīsī possibly took al-Bīrūnī as a model, who cites in his book of drugs, *Kitāb aṣ-Ṣaidana,* names for many drugs in about ten languages, amongst them "almost always Greek, Syriac, Persian, Indian, but often also Hebrew and the languages of Central and South Asia (Khwarezmian, Balkhian, Tokharian, Zabūlian, Sijistānian, Sindhi, among others)," see M. Meyerhof, *Das Vorwort zur Drogenkunde des Bērūnī,* in: Quellen und Studien zur Geschichte der Naturwissenschaften und der Medizin (Berlin) 3/1933/157-208, esp. p. 170 (reprint in: Islamic Medicine, vol. 96, pp. 171-240, esp. p. 184).

[230] v. C. Brockelmann, *Geschichte der arabischen Litteratur,* vol. 1, p. 280, suppl. vol.1, p. 492.

[231] The only manuscript known to me is in İstanbul, Topkapı Sarayı, III. Ahmet 2707 (649 H.), v. the catalogue by F. E. Karatay, vol. 4, p. 29.

[232] Judged by the type of blessing formula which follows the name az-Zauzanī and the absence of a blessing formula in the case of al-Maidānī, an-Nasafī appears to have been a younger contemporary of the latter.

[233] v. C. Brockelmann, op. cit., vol. 1, p. 288, suppl. vol.1, p. 505.

[234] v. ibid., vol. 1, p. 289, suppl., vol. 1, pp. 506-507.

[235] I do not take into account the book *Muqaddimat al-adab* by Maḥmūd b. ʿUmar az-Zamaḫšarī (d. 538/1144) as an Arabic-Persian dictionary of the 6th/12th century. The Persian, Turkish and Mongolian glosses which are available in various manuscripts seem to be later interpolations, see Heinz Grotzfeld, *Zamaḫšarīʿs muqaddimat al-adab, ein arabisch-persisches Lexikon?* in: Der Islam (Berlin) 44/1968/250-253.

things, this book describes a ballistic crossbow (*qaus az-ziyār*) said to be the largest, the farthest in reach and the most effective ever made. A geared winch mechanism allowed for its large bow, made of several layers of wood and horn glued together, to be drawn by merely one or two men (instead of about twenty). In the 13th century this type of crossbow also started to appear in the West. This probably kindled Leonardo da Vinci's fantasy, who drew a gigantic specimen of such a weapon (infra V, 119). It seems that the crusade invasions gave the impulse for the Muslims of Syria and Egypt to search for the most effective means of defence possible. The process of developing such weaponry continued into the 7th/13th and 8th/14th centuries.

[41] The 7th/13th Century

In all branches of science, the 7th/13th century provides evidence of creativity in the further development of those disciplines that were cultivated in the preceding century. Yet it is characteristic of this century that the subject matters inherited from earlier generations were as far as possible subjected to systematization. They were established for the first time as strictly defined disciplines or revised in order to account for the progress made in the course of time. To begin with, we may say that the last-mentioned type of continuation process offers its best examples in Naṣīraddīn aṭ-Ṭūsī's revisions (*taḥrīr*) of important works by Greek and Arabic scholars.

An unfortunate opinion, brought into circulation at some point or other in complete ignorance of the history of Arabic-Islamic science and contradicting historical facts, states that this century already carried in it the beginnings of stagnation. The opposite is true.

The progress made in the theoretical branch of astronomy shows itself in the attempts to reform the Ptolemaic planetary models (supra, p. 25), once started by Ibn al-Haiṯam and Abū ʿUbaid al-Ǧūzağānī. In order to restore the principle of uniform circular motion in the orbits—a principle that Ptolemy had violated with the introduction of the equant into his planetary model—Naṣīraddīn aṭ-Ṭūsī made a ground-breaking attempt. In his model he retains the centre of the equant, so that the length of the eccentricity is equal to the diameter of the epicycle, while the mid-point of the eccentricity becomes the centre of the deferent, along which the centres of the epicycles of planets move from the east to the west, covering the same distances (towards the east) in the same periods. Naṣīraddīn eliminates the resulting violation of the uniformity of motion by introducing a model of double epicycles in which a smaller circle (with a radius equal to half of the radius of the larger circle and therefore half of the length of the eccentricity) rotates inside a larger circle (between its centre and the circumference) in the opposite direction from west to east.[236] Naṣīraddīn bases his model on an original lemma which states:[237] "In a circle, let a small circle roll. If its radius is half that of the large circle, then any point on the small circle, while rolling, describes a diameter of the large circle."[238] This theorem appears later in the works of Copernicus (d. 1543), Ludovico Ferrari (d. 1565) and Philippe de La Hire (d. 1718).[239]

Shortly after Naṣīraddīn aṭ-Ṭūsī, Muʾaiyadaddīn al-ʿUrḍī (fl. before 670/1272) and Quṭbaddīn aš-Šīrāzī (d. 710/1311) developed two new models resembling each other to a large extent, where the younger scholar seems

[236] F. Sezgin, op. cit., vol. 6, p. 35

[237] v. *at-Taḏkira fī ʿilm al-haiʾa*, MS Paris, Bibliothèque nationale, ar. 2509, fol. 37b-38a; French transl. by Bernard Carra de Vaux, *Les sphères célestes selon Nasîr-Eddîn Attûsî*, in Paul Tannery, *Recherches sur l'histoire de l'astronomie ancienne*, Paris 1893, appendice VI, pp. 337-361, esp. p. 348 (reprint in: Islamic Mathematics and Astronomy, vol. 50, pp. 161-185, esp. p. 172).

[238] M. Curtze, *Noch einmal über den de la Hire zugeschriebenen Lehrsatz,* in: Bibliotheca Mathematica (Berlin) 9/1895/33-34: M. Cantor, *Geschichte der Mathematik*, op. cit., vol. 1, p. 780; J. Tropfke, *Geschichte der Elementar-Mathematik,* vol. 4, 2nd ed. Berlin and Leipzig 1923, p. 126.

[239] J. Tropfke, op. cit., vol. 4, p. 126.

to be depend-ent on the older. This resulted in an interesting model for Mercury.[240]

Amongst the most remarkable achievements of the 7th/13th century in the field of astronomy ranks the foundation of the observatory at Maragha south-east of the Lake Urmiya. The project was accomplished under the leadership of Naṣīraddīn aṭ-Ṭūsī between ca. 657/1259 and 668/1270 upon [42] commission of Hülägü, founder of the western Mongol empire, by a group of astronomers who originally worked in Baghdad and Syria. With a main building planned in large scale for the purpose of astronomical observation and with large instruments, some of which built for the first time, this undertaking was of epochal importance in the history of observatories in the Arabic-Islamic culture area. We can trace its after-effects not only in the Islamic world until the 16th century but also in Europe, where they began in the middle of the 16th century.

The spirit of logical systematization and elaboration of the work accomplished by the predecessors is characteristic of this century. One of the most significant examples of this is provided by Naṣīraddīn aṭ-Ṭūsī in his *Kitāb aš-Šakl al-qaṭṭāʿ* with which he established trigonometry as an independent discipline. For a long time this achievement had been credited to J. Regiomontanus, until, towards the end of the 19th century, A. von Braunmühl pointed out the facts of the matter (infra III, 135f.). The polar triangle, or supplementary triangle, a basic element of spherical trigonometry which appears in Europe for the first time in the work of François Viète (1540-1603), goes back to Naṣīraddīn as well. Although it had already been introduced by Abū Naṣr b. ʿIrāq, it was Naṣīraddīn who gave a first clear description of it.[241]

A revision of Euclid's *Elements* not identical with the one by Naṣīraddīn aṭ-Ṭūsī but most probably going back to his century, was published in Rome in the year 1594 as a work by aṭ-Ṭūsī. It, too, betrays the spirit specific to the Arabic-Islamic science of the 7th/13th century and strongly influenced the subsequent generations of mathematicians. In the chapter Geometry of this catalogue (infra III, 127), aṭ-Ṭūsī's role in connection with the further development of the theory of parallels, which in the 18th century led to non-Euclidian geometry, will be mentioned; besides this, mention must be made here of his contribution to the theory of compound ratios. His theory of the "Measurements of Proportions" reappears in the "Denominations of Proportions" by Gregorius a Sancto Vincentio (1584-1667).[242]

The achievements of the same century in the field of mathematical geography were prodigious both in quantity and quality, and were often of ground-breaking significance.

In the western part of the Islamic world, Abu l-Ḥasan al-Marrākušī (b. around 600/1203, d. ca. 680/1280) described a method for establishing the time difference between localities and thereby their longitudinal difference through the altitude of fixed stars above the eastern or western horizon, to be measured with an astrolabe.[243] Al-Marrākušī also described a procedure which enables the solution of this problem without the use of the astrolabe. The problem and its solution, described in the 10th volume of my *Geschichte des arabischen Schrifttums,* involves in its most general form the calculation of the hour-angle of a star from its altitude and azimuth, the rotation

[240] v. *The astronomical work of* Muʾayyad al-Dīn al-ʿUrḍī. *A thirteenth century reform of Ptolemaic astronomy. Kitāb al-Hayʾah*, ed. by George Saliba, Beirut 1990

[241] v. F. Sezgin, op. cit., vol. 5, pp. 57 ff. and infra III, 133 ff.

[242] v. A. P. Juschkewitsch, op. cit. p. 255; F. Sezgin, op. cit., vol. 5, p. 58.

[243] Abu l-Ḥasan al-Marrākušī, *Ǧāmiʿ al-mabādiʾ wa-l-ġāyāt*, facsimile edition Frankfurt 1984, vol.1, pp. 153-154, 160; C. Schoy, *Längenbestimmung und Zentralmeridian bei den älteren Völkern*, in: Mitteilungen der K.K. Geographischen Gesellschaft Wien 58/1915/25-62, esp. pp. 39-43 (reprint in: Islamic Geography, vol. 18, pp.36-71, esp. pp. 48-52); F. Sezgin, op. cit., vol. 10, p. 170.

of the celestial dome from its transit through the meridian, and the declination.[244]

[43] Yet neither the method of determining the hour-angle nor the use of spherical trigonometry for the determination of longitudinal differences appear for the first time in al-Marrākušī's writings. Al-Bīrūnī had already placed the rules for the spherical triangle, discovered by his teachers, in the service of mathematical geography. Amongst subsequent generations we find—tangibly for us in the case of al-Marrākušī—a further development in which all trigonometric-astronomical tools are improved in a systematic manner for a precise determination of local time through the observation of fixed stars. This technique of astronomical observation, in which correct ascensions and declinations increasingly come to the fore as a system of reference, is encountered in the West with Tycho Brahe in the second half of the 16th century.[245]

It seems that Abu l-Ḥasan al-Marrākušī actually applied the special case of determination of longitude in question for geographical purposes. He left us a table of coordinates comprising about 130 localities. The importance of this table for the history of geography lies in the fact that it contains corrected latitudes and much improved longitudes of coastal towns of the Mediterranean and of further localities on the Iberian peninsula and in Northern Africa; from these it can be established that the length of the Mediterranean—with an improvement of about 19° as compared to Ptolemy's geography and of about 8° compared to the result of the Ma'mūn geographers—approaches the modern value up to 2° or 3°; the longitudinal difference between Toledo and Baghdad found as 51°30' also shows a similar far-reaching improvement.

It goes without saying that such a profound improvement of the coordinates of a vast geographical area stretching from Spain to Baghdad could not possibly have been achieved by a single person and not even in one single generation. Abu l-Ḥasan al-Marrākušī indeed makes no such claim. On the contrary, he points out that he marked his own coordinates with red ink in his autograph in order to distinguish them from older ones.[246] In the middle of the 19th century, the geography historian Joachim Lelewel[247] recognised the significance of these corrections and described them as a "reform of geography". He noticed that through the "extremely useful operation" Spain lost its "disproportionately large dimension" found in earlier cartography, whereby "the sides of Africa were pressed southwards while a large part of Spain moved north and protruded westwards." Through al-Marrākušī's corrections, all the localities in the Maghrib are raised in latitude and thus given their actual positions.

It seems to be adequately documented today[248] that the beginnings of astronomical-geographical attempts at mathematically surveying as much of the areas west and east of Baghdad as possible took place in the first half of the 5th century, independently from one another. One of the consequences of the measurements taken in the western areas was that the prime meridian passing through the Canary Islands, which was adopted from Marinus/Ptolemy, had to be shifted westwards by 17°30', i.e. to 28°30' west of Toledo in the Atlantic Ocean. After this correction of the longitudes in the western part of the Islamic world, the corrected values for Rome and Constantinople appear in one of the oldest surviving tables as 45°25' and 59°50' respectively. Subtracting 28°30' from both (Rome 16°50'; Constantinople 31°20'), these values are, compared to the modern ones (Rome 16°30'; [44] Istanbul 32°57') merely 20' too large or 1°37' too small respectively. The longitude of Baghdad was now established at 80° with a dif-

[244] v. F. Sezgin, op. cit., vol. 10, pp. 168-171

[245] v. F. Sezgin, op. cit., vol. 10, p.171.

[246] v. F. Sezgin, op. cit., vol. 10, p.171.

[247] *Géographie du moyen âge*, vol. 1, Brussels 1852, p. 138; F. Sezgin, op. cit., vol. 10, p. 172.

[248] v. F. Sezgin, op. cit., vol. 10, p. 154-167.

ference of 51°30' to Toledo and a distance of 10° to the central meridian in the east:[249]

Prime meridian | Canary Islands | Toledo | Baghdad | Central meridian
17 | 11 | 51 | 10
0 | 17 | 28 | 80 | 90

In his book *Asie centrale* (1843) Alexander von Humboldt pointed to the fact that the duplicate prime meridians are also mentioned in the tables of the *Libros del saber de astronomía* (compiled between 1262 and 1272 CE upon commission of Alfons of Castile).[250] We are in the position today to demonstrate that tables prepared according to both prime meridians found their way into Europe beyond Spain from the first half of the 12th century. At first those tables appeared slowly, but later, from around the beginning of the 14th century into the 18th century, started to mushroom and amount to several hundred; upon examination they turn out to be either corrupt copies or mixed tables derived from various Arabic originals which contained data according to either of the two prime meridians and which in turn sometimes still drew on Ptolemaic tables.[251]

We may also refer to the fact, dealt with at length in the *Geschichte des arabischen Schrifttums*[252], that European graduated world maps from the second decade of the 16th century up to the 18th or even 19th century betray a dependence on longitudes gleaned from either one type or a mixture of Arabic tables. Yet we must stress that this statement does not imply that those maps were drawn by Europeans according to coordinates found in Arabic tables. They are copies or compilations of maps of unequal quality that where occasionally brought to Europe from the Arabic-Islamic world.

The substantial corrections of longitudes in the area between the western border of the oikoumene and Baghdad which were achieved by geographers and astronomers of the western school of Islamic science from the 5th/11th century onwards, at first escaped most eastern Arab scholars. Although in a few tables from the eastern part of the Islamic world such corrections are found even in the 5th/11thcentury,[253] they are restricted to places located west of Baghdad. No serious attempt at unification of the corrections of the longitudes to the west as well as to the east of Baghdad obtained since the middle of the 5th/11th century, i.e. to transform also the eastern longitudes counted from Baghdad according to the prime meridian 28°30' west of Toledo, was made for almost three centuries.

This breakthrough, revolutionary for the history of cartography, finally occurred as a result of the collaboration of the "eastern" astronomer Naṣīraddīn aṭ-Ṭūsī and a scholar from the west, Muḥyiddīn Yaḥyā b. Muḥammad b. Abi š-Šukr al-Maġribī (d. ca. 680/1281) shortly before 670/1272 at the newly founded observatory of Maragha. The integration of longitudes was carried out consistently in the astronomical tables of the two scholars, namely, the *az-Zīǧ al-Īlḫānī* and the *Adwār* [45] *al-anwār mada d-duhūr wa-l-akwār*.[254]

Considering that the extensive comparative geographical tables of places by Abu l-Fidā' Ismā'īl b. 'Alī (d. 732/1331) do not yet include the substantial corrections on the area west of Baghdad, we are indeed justified in calling the integration of the coordinates as achieved in Marāġa a revolutionary breakthrough in the history of cartography. The scope of this project is illustrated by two examples. The longitudinal difference between Toledo (28°30') and Ghazna

[249] v. F. Sezgin, op. cit., vol. 10, p. 162.

[250] v. C. Schoy, *Längenbestimmung und Zentralmeridian bei den älteren Völkern*, op. cit. p. 54 (reprint, op. cit. p. 63); F. Sezgin, op. cit., vol. 10, pp.162, 213.

[251] v. F. Sezgin, op. cit., vol. 10, pp. 205-267.

[252] vol. 11, pp. 85-154.

[253] v. ibid., vol. 10, p. 164.

[254] v. F. Sezgin, op. cit., vol. 10, pp. 177 ff. Traces of inconsistent integration are found, for example, in the tables of Kūšyār b. Labbān (1st half 5th/11th c.), in the anonymous *Dastūr al-munaǧǧimīn* (2nd half 5th/11th c.) and in the works of Abu l-Ḥasan al-Marrākušī.

(104°20') is reduced to 75°50' with a relatively minor error of 3°28' as compared with the modern value of 72°22'. The difference between Rome (45°27') and Daibul in India (102°30') is 57°03' with an even smaller error of 1°48' compared to the modern value of 55°15'. Only from the 19th and 20th century did European cartographers gradually succeed in correcting these longitudinal differences further.

The first world maps drawn according to the fundamentally corrected coordinates were presumably produced as early as in the second half of the 7th/13th century. There is evidence leading to such an assumption involving a presently lost manuscript which perhaps was an autograph of the astronomical *at-Taḏkira fī l-haiʾa* by Naṣīraddīn aṭ-Ṭūsī which appears to have contained such a world map. A copy[255] drawn after the original by Joseph Needham[256] and published in 1959, though a mere sketch, shows a basic depiction of the oikoumene surrounded by the ocean, which is more advanced than that on the Maʾmūnian world map and the one by al-Idrīsī; this includes the fact that the west-eastern extension of the oikoumene is considerably reduced.[257]

According to a report[258] found in an historic work from the turn of the 7th/13th to the 8th/14th century to which historians of cartography have failed so far to pay any attention, a world map was drawn upon a papier-mâché globe at the Baghdad observatory under Naṣīraddīn aṭ-Ṭūsī in the year 664/1265. This agrees with a passage in the Records of the Yuán-dynasty by Sóng Lián (1310-1381 CE) referring to astronomical instruments imported into China from the West (i.e. the Central Asia). It describes six astronomical instruments and a terrestrial globe which were presented in the year 1271 (i.e. three years before Naṣīraddīn aṭ-Ṭūsī died) by one Ǧamāladdīn to the Mongol sovereign Qubilai Ḫān. The terrestrial globe is said to have been made of wood, the 'seven waters' on it drawn in blue-green and the three continents with their rivers, lakes etc. are said to have been drawn 'bright' (white). 'Small squares' are said to have been marked in such a way that it was possible to calculate the size of regions and the distances of all routes.[259] Those 'small squares' doubtless refer to the network of meridians and parallels of a graticule. We may also mention that the envoy Ǧamāladdīn has been identified as the first director of the observatory founded by Qubilai in the Mongol realm. Moreover, Ǧamāladdīn authored a geography of the entire dominions. However, only a few fragments of this comprehensive work have survived incorporated into later compilations.[260]

[46] There is still further evidence in favour of our assumption that the oldest maps of the world that reflect the substantially improved coordinates of the 5th/11th century were produced as early as in the second half of the 7th/13th century. They will be mentioned in the context of the geographical endeavours of the 8th/14th century. Concluding the discussion of noteworthy achievements of the 13th century, the emergence of perfect or near-perfect maps of the Mediterranean and of the Black Sea shall be mentioned. They are commonly referred to as "portolan charts" by modern history of cartography. The origin of the oldest maps of this type known in the European culture area is dated around the turn of the 13th to the 14th century. The question of their origin has been discussed for about the last 150 years. With the exception of a few Arabists who noted a certain affinity of these charts with al-Idrīsī's world map, the issue has so far been treated in complete ignorance of the achievements of the Arabic-Islamic culture area in the field of mathematical geog-

[255] *Science and Civilisation in China*, vol. 3, London, New York, Melbourne 1959, p. 563.

[256] v. F. Sezgin, op. cit., vol. 12, p. 36, map no. 15.

[257] v. ibid, vol. 10, pp. 138 ff., 310.

[258] v. ibid, vol. 10, pp. 310-311.

[259] On the sources, v. ibid, vol. 10, pp. 311-312.

[260] v. ibid., vol. 10, p. 312.

raphy. Hence it was understandably not known that in the Arabic-Islamic culture area the west-eastern dimensions and distances between, e.g., Tangier and Rome, Toledo and Rome, Rome and Alexandria or Rome and Constantinople were already established with an accuracy that comes close to the modern values. These accurate data constitute the decisive element serving to elucidate the progress made between the fairly realistic shape of the Mediterranean in Idrīsī's map and the shape of the so-called perfect portolan charts with their linear networks. In several chapters of the volumes 10 and 11 of my *Geschichte des arabischen Schrifttums,* I have tried to explain my opinion of a long historic evolution of the cartographic depiction of the Mediterranean. Various cultures made their contributions in the course of that development, the finally leading to the so-called portolan charts which can be ascribed to the Arabic-Islamic culture area. The circular world map, appended by Brunetto Latini to his *Livres dou tresor* (ca. 1260-1266), is an important document for the stage of development between al-Idrīsī's world map (549/1154) and the almost perfect shape of the Mediterranean and the Black Sea with the adjacent areas, achieved presumably in the 2nd half of the 7th/13th century. As Florentine ambassador in Toledo and Sevilla, Latini had the opportunity to acquaint himself with the adoption of Arabic-Islamic sciences which was then in full swing. He also helped Dante Alighieri deepen his knowledge of Islam.[261] His world map appeared without precedence in Italy and differs fundamentally from the old *Imago mundi* maps circulating in 13th century Europe. It seems to be a copy of a model from the Arabic-Islamic culture area, ultimately going back to the Ma'mūn map, yet showing a certain progress regarding the shapes of the Mediterranean, Asia Minor and Africa. It does not however reflect the advances made in the depiction of North, North East and Central Asia known from the Idrīsī map. It must be also noted that the Brunetto Latini map is southern-oriented as was the Arab custom. The representation of mountains and highlands in elevation corresponds to the same practice in the Ma'mūn map.[262]

Besides the Brunetto Latini map, which we assume to be a copy of a map from the western part of the Islamic world, there are a few more maps that outline the progress made in the second half of the 7th/13th century in the depiction of Asia. They are the five maps which Marco Polo is said to have brought back from his journey.[263] [47] Without entering the discussion on whether or not Marco Polo actually reached China,[264] we point out that on his outward journey (1272) he visited western Iran under the reign of the Ilkhans and on his homeward journey (1294/1295) he visited Tabrīz. This was the region where mathematical geography and, based on it, the new cartography was cultivated most intensively. In Marāġa and later in Tabrīz, the capitals of the Ilkhans, new centres of the sciences arose from whence books, instruments, maps and further materials found their way to the West, mostly via Constantinople. The maps brought back by Marco Polo, the authenticity of which I have discussed in the *Geschichte des arabischen Schrifttums* are rather clumsy copies;[265] however, they contain, on the one hand, the oldest cartographic representation of South Asia extant and, on the other, an orthogonal graticule showing the eastern edge of Asia at 140°. It is the eastern border of the oikoumene, which according to Ptolemy was at 180° and which was reduced largely to its true value by Arabic-Islamic astronomers only in the 7th/13th century.[266]

[261] v. M. Asín Palacios, *La escatología musulmana en la Divina Commedia*, Madrid 1961, pp. 381-386; F. Sezgin, op. cit., vol. 10, p. 223.

[262] v. F. Sezgin, op. cit., vol. 10, pp. 327-330.

[263] v. ibid, vol. 10, pp. 315-320.

[264] v. ibid, vol. 10, p. 318, note 2.

[265] v. ibid, vol. 10, pp. 315-319.

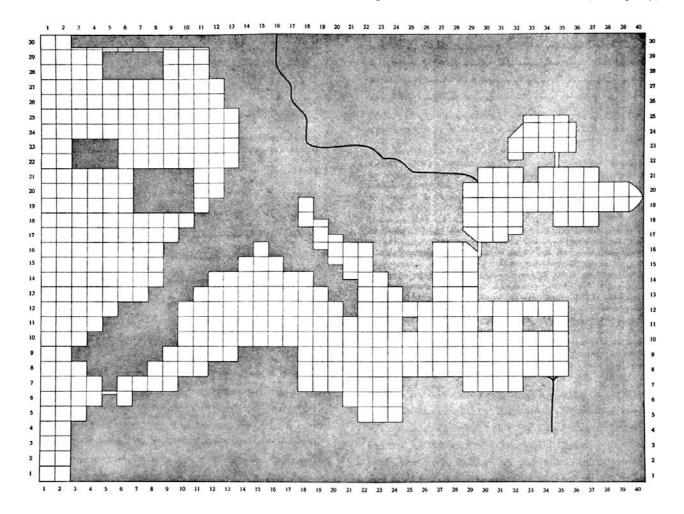
[266] v. ibid, vol. 10, pp. 317-318.

The type of world map developed in the Arabic-Islamic culture area in the second half of the 7th/13th century soon spread not only to Europe and but also to China. In the early 14th century, maps started to appear there that break with the conventional Chinese concept of the Earth's surface and with the cartographic tradition. Towards the middle of the last century these maps came into the focus of research.[267] When the surviving younger versions of those maps were examined, it came as a surprise that they show Africa in triangular shape, that they represent the configuration of the Mediterranean almost correctly, and that they, moreover, reproduce the Arabised names of about 100 places and countries in Europe and—as far as could as yet be identified—35 from Africa. The appearance of that type of map which "in its origins goes back to the years around 1300" in China has been explained by research almost unanimously with an Arabic model. This model is supposed to have been the graduated terrestrial globe which was brought from Marāġa to Da Du (Beijing) by the above-mentioned astronomer and geographer Ǧamāladdīn in the year 1267, to be handed, together with six astronomical instruments, to the ruler Qubilai Ḫān. This assumption may be correct, but I am more inclined to believe that planispheric world maps from the east of the Arabic-Islamic world reached China—shortly after their appearance—as well. Certainly the numerous place names would fit more easily on maps than on a terrestrial globe.

I take the liberty of bringing to the notice of a wider circle of readers my cartographic-historic evaluation of those maps from the relevant volume of my *Geschichte des arabischen Schrifttums*[268] which appeared in 2000: "The eminently important historical fact in geography, namely that—more or less at exactly the same time at which a new type of world map and portolan chart appeared in Europe—the cartography of the Chinese, which until that time had restricted itself to China and parts of East Asia, broke with this tradition and extended the borders of its image of the world all the way to the Atlantic and from South Africa through to central Russia, whereby simultaneously an almost exact configuration of the Mediterranean and of the triangular shape of Africa became recognisable, is something which has not been taken into consideration in the discussion on the origin of the portolan charts as far as I am aware. The phenomenon of [48] this simultaneously-timed emergence of a practically identical new image of the world in Europe and China should, in my opinion, lead historians of geography to the assumption that a common model existed. Not only the Islamic cultural area provides us with sufficient cartographic and mathematical-geographical documents which prove that the sought after models are to be found in that period of the history of sciences which was shaped by that cultural area."

The oldest surviving Arabic document of this latest stage of development is a map from the Maghreb.[269] It shows the westernmost part of the Mediterranean with a complete configuration of the Iberian Peninsula and the western edge of Europe with some strips of the English and Irish coastline. This Maghribi map may be older than the oldest known "portolan chart" which is supposed to date from around 1300 CE. In any case, the first scholar who wrote about it, Gustavo Uzielli,[270] introduced it as a work of the 13th century. A few years later Theobald Fischer,[271] in the context of his work on medieval world and sea maps, was inclined to shift its origin to

[267] v. F. Sezgin, op. cit., vol. 10, pp. 321-326.
[268] v. ibid., vol. 10, p. 326.

[269] v. F. Sezgin, op. cit., vol. 11, pp. 27-31.
[270] *Studi biografici e bibliografici sulla storia della geografia in Italia*, 2nd ed., vol. 2, Rome 1882, p. 229; Theobald Fischer, *Sammlung mittelalterlicher Welt- und Seekarten italienischen Ursprungs und aus italienischen Bibliotheken und Archiven,* Marburg 1885 (reprint, Amsterdam 1961 without maps), p. 220; F. Sezgin, op. cit., vol. 11, pp. 27-28.
[271] Th. Fischer, op. cit., p. 220.

the end of the 14th century; and because of this, later research lost sight of one milestone in the history of development of the 'portolan charts'. The pull of conventional mediaeval studies unfortunately quite often keeps researchers from addressing issues of the date and provenance of technological innovations and new scientific or philosophical concepts surfacing in Europe (outside Spain) from the 12th century onwards in the context of the reception and assimilation of Arabic-Islamic sciences in general. The case of the 'portolan charts' makes no exception.

In support of my view regarding the character and quality of the cartographic skills found in the Islamic world in the 7th/13th century, I would like to cite one more testimony for which we are indebted to one of the pivotal figures in this development. I am referring to the polymath Quṭbaddīn aš-Šīrāzī (d. 710/1311) mentioned above (supra p. 41). In connection with matters of geography, included in his astronomical work *at-Tuḥfa aš-šāhīya fi l-hai'a*, he deals with the cartographic depiction of the oikoumene and the difficulty of fitting indispensable details in small formats. To this end he proposes a practical method of laying out a simplified and schematized map of the Mediterranean. Together with the Black Sea, the Mediterranean is projected on a rectangular frame divided into 1200 squares. The longitudes and latitudes are measured in squares rather than degrees.

Apparently oceans and continents were distinguished by colour. In the first half of the 20th century some Arabists drew up such a schematic map on the basis of Quṭbaddīn's data (infra p. 49). The shapes of North-Africa, the Mediterranean, the Black Sea and the depicted parts of Europe leave hardly any room for doubt that Quṭbaddīn

already knew the accurate geographical representation of those areas as found in the portolan charts. In fact it is quite evident that Quṭbaddīn took his data from a map at hand.[272] In corroboration of this, we can cite the universal scholar Rašīdaddīn's (d. 718/1318) report [49] to the effect that Quṭbaddīn aš-Šīrāzī presented a detailed map of the Mediterranean to the Mongol ruler Arġūn on 13th Šaʿbān 688 (1 September 1289). On this map, the coasts, bays, and cities in the West and in the North and even details of the Byzantine territory were inscribed.[273]

After discussing the progress made in cartography in the Islamic world during the 7th/13th century, we may now turn to an apex of geographical lexicography. I am referring to the "Geographical Dictionary" (*Muʿǧam al-buldān*) by Yāqūt b. ʿAbdallāh ar-Rūmī al-Ḥamawī[274] (b. 574/1178, d. 626/1229). Yāqūt was primarily a man of letters and a philologist. In the field of literature he wrote a number of noteworthy works, including his biographical dictionary of scholars entitled Iršād al-arīb or *Muʿǧam al-udabāʾ*, which counts amongst the most important works of its kind extant. In the field of geography, his lexical interest brought about two books. One of them, *al-Muštarik waḍʿan wa-l-muftariq ṣaqʿan* of 623/1226, deals with geographical homonyms. The other one, *Muʿǧam al-buldān,* marks the climax of the literary genre of geographical dictionaries which had continued to develop in the Islamic world from the 4th/10th century onwards. Besides lexical sources, Yāqūt digested a number of titles of descriptive regional geography and mathematical geography as well as travelogues. Thus his work [50] became an invaluable source for the historiography of sciences and culture of the Arabic-Islamic world. In the commendable edition by Ferdinand Wüstenfeld (1866-1870), the book runs into 3500 pages. Comparing Yāqūt's book in quantity and quality with the first modern geographical dictionary to appear in Europe, the Latin *Synonymia geographica*[275] by Abraham Ortelius (1578), gives a fairly good idea of the significant development of this branch of scientific literature in the Arabic language.

Turning to the field of medicine, a significant discovery in that century—which the historian of medicine L. Leclerc,[276] referring to Syria, called a golden age of sciences, and medicine in particular—was that of the minor circulation of blood by ʿAlī b. Abi l-Ḥasan Ibn an-Nafīs al-Qurašī (d. 687/1288). Researching for his thesis[277] on Ibn an-Nafīs' commentary on the surgery chapter of the *al-Qānūn fi ṭ-ṭibb* by Ibn Sīnā, Muḥyiddīn aṭ-Ṭaṭāwī, an Egyptian student, hit upon that fact in the year 1924. Thanks to several studies by Max Meyerhof and Joseph Schacht,[278] we know today that this discovery by Ibn an-Nafīs was borrowed by Michael Servetus (Miguel Servet) for his *Christianismi restitutio* (Vienna 1553); consequently the latter was considered its originator for centuries. Realdus Columbus (Realdo Colombo) in his *De re anatomica libri XV* (Venice 1559) also seems to have known about the discovery directly or indirectly from Ibn an-Nafīs. Ibn an-Nafīs' description of the pulmonary circulation which

[272] v. F. Sezgin, op. cit., vol. 10, pp. 313-314.

[273] v. F. Sezgin, op. cit., vol. 10, pp. 312-313.

[274] v. C. Brockelmann, *Geschichte der arabischen Litteratur*, vol. 1, pp. 479-481, suppl., vol. 1, p. 880.

[275] v. J.-T. Reinaud, *Notice sur les dictionnaires géographiques arabes,* in: Journal Asiatique (Paris), 5e série 16/1860/65-106, esp. p. 67 (reprint in: Islamic Geography, vol. 223, pp. 1-42, esp. p. 3).

[276] *Histoire de la médecine arabe*, vol. 2, Paris 1876 (reprint, Islamic Medicine, vol. 49), p. 157; M. Meyerhof, *Ibn an-Nafīs und seine Theorie des Lungenkreislaufs*, in: Quellen und Studien zur Geschichte der Naturwissenschaften und der Medizin (Berlin) 4/1935/37-88, esp. p. 40 (reprint in: Islamic Medicine, vol. 79, pp. 61-134, esp. 64).

[277] *Der Lungenkreislauf nach el Koraschi. Wörtlich übersetzt nach seinem 'Kommentar zum Teschrih Avicenna'…* by Mohyi el Din el Tatawi, Freiburg 1924 (type-written thesis, reprint in: Islamic Medicine, vol. 79, pp. 1-25)

[278] Studies on this subject published up to 1957 were collected and edited in: Islamic Medicine, vol. 79.

he gave in his commentary to the *Qānūn* of Ibn Sīnā supposedly reached Europe through a translation by Andreas Alpagus (Andrea Alpago, d. ca. 1520).[279] During a thirty-year stay in Syria, he had acquainted himself with Arabic language and medicine. On his return to Padua he took with him several Arabic books and translated, inter alia, Ibn Sīnā's *Qānūn* into Latin, the same *Canon* which had already been translated by Gerard of Cremona.

With regard to yet another medical scholar of the 7th/13th century, research found clues of an important discovery. While staying in Cairo, the versatile physician and brilliant natural historian ʿAbdallaṭīf b. Yūsuf b. Muḥammad al-Baġdādī (b. 557/1162, d. 629/1232) seized the opportunity to examine the skeletons of people who had perished during a plague epidemic and famine in the year 598/1202. He wrote about his observations and the results of his examinations in his anthropogeographical book on Egypt entitled *Kitāb al-Ifāda wa-l-iʿtibār fi l-umūr al-mušāhada wa-l-ḥawādiṯ al-muʿāyana bi-arḍ Miṣr,* in which he dealt, inter alia, [51] with stones, flora and fauna, antiquities, architecture and the local cuisine. In his anatomical study of thousands of skeletons he revised the errors and inaccuracies of his predecessors, in particular of Galen. One of his findings was that the human mandible consists of one bone only, rather than two bones joined at the chin as Galen believed.[280] In this context al-Baġdādī points out that the evidence of one's own observation was more reliable than the doctrines of Galen, despite the high rank befitting the latter.[281]

The maturity of the epoch with its widened horizon as well as the extent and the magnitude of the achievements accomplished in his culture area induced Aḥmad b. al-Qāsim Ibn Abī Uṣaibiʿa (d. 668/1270), a contemporary of the above-mentioned Ibn an-Nafīs and ʿAbdallaṭīf al-Baġdādī, to compose, within the scope of his resources, a universal history of medicine. The medical historian Edith Heischkel,[282] even though she unfortunately characterises the epoch of the author incorrectly as "a late period of Arabic science in which existing knowledge was digested rather than being creative in its own right", described quality and character of this work entitled *ʿUyūn al-anbāʾ fī ṭabaqāt al-aṭibbāʾ* quite appropriately: "He has set himself free from the bias of antique and Jewish myths, knowing that each and every culture has its own peculiar theory of the origins of medicine. In his view, each culture also has its own special medicine, one yielding place to another in the course of centuries. He doubted whether it was at all feasible to deem the medical science of any one people the oldest. The Arab, in whose native region cultures of diverse people from East and West fused, possessed the universal historical scope which no physician before him ever had; in the writings of Ibn Abī Uṣaibiʿa the history

[279] Edward C. Coppola, *The discovery of the pulmonary circulation: A new approach,* in: Bulletin of the History of Medicine (Baltimore) 31/1957/44-77 (reprint in: Islamic Medicine, vol. 79, pp. 304-337); Charles D. O'Malley, *A Latin translation of Ibn Nafis (1547) related to the problem of the circulation of the blood*, in: Journal of the History of Medicine and Allied Sciences (Minneapolis) 12/1957/248-253 (reprint in: Islamic Medicine, vol. 79, pp. 338-343)

[280] L. Leclerc, *Histoire de la medécine arabe*, vol. 2, pp. 182-187, esp. pp. 184-185 (reprint in: Islamic Medicine, vols. 48-49); *The Eastern Key. Kitāb al-Ifādah waʾl-iʿtibār of ʿAbd al-Laṭīf al-Baghdādī*. Translated into English by Kamal Hafuth Zand and John A. and Ivy E. Videan, London 1965, pp. 272-277.

[281] Free summary of the following Arabic text: *Fa-inna Ǧālīnūs wa-in kāna fi d-daraǧa al-ʿulyā fi t-taḥarrī wa-t-taḥaffuẓ fī-mā yubāširuhū wa-yaḥkīhī, fa-inna l-ḥiss aṣdaq minhu*, cf. *Abdallatif's eines arabischen Arztes Denkwürdigkeiten Egyptens in Hinsicht auf Naturreich und physische Beschaffenheit des Landes und seiner Einwohner, Alterthumskunde, Baukunde und Ökonomie...* translated from the Arabic and explained by S. F. Günther Wahl, Halle 1790, pp. 342-343.

[282] *Die Geschichte der Medizingeschichtsschreibung*, in the appendix of: Walter Artelt, *Einführung in die Medizinhistorik. Ihr Wesen, ihre Arbeitsweise und ihre Hilfsmittel,* Stuttgart 1949, pp. 201-237, esp. p. 205.

of medicine is seen from the point of view of universal history for the first time."

"… The Western historians of medicine had to go a long way until they finally came to these insights. Medical historians in the West observed, what the Arab cosmopolitan attitude had long before seen, only after they had overcome the authority of antiquity and of the Bible.[283]

Finally, in the field of medicine of the 7th/13th century, the hospital built 683/1284 in Cairo by the Mamluk Sultan al-Malik al-Manṣūr Saifaddīn Qalāwūn[284] shall be mentioned. After the ʿAḍudī hospital in Baghdad (372/981) and the Nūraddīn hospital in Damascus (549/1152), it was the latest and the most advanced of the three major hospitals in the Islamic world established by that time. In some respects it seems almost modern. Such progressive features are its medical organisation with specialised treatments, the playing of music to patients suffering from mental illness or insomnia, in-house medical training, [52] an elaborate administration, financial security through sufficient income from an endowment (with quite interesting conditions specified in the foundation deed) and, finally, the building itself and its equipment. This hospital with its dome (which seems to have collapsed after the 11th/17th century) and its cruciform ground plan is believed to have served as the model for similar hospitals in Europe.[285]

The 7th/13th century also marks a climax in music theory as part of the natural sciences. After the assimilation of predominantly late antique sources by Yaʿqūb b. Isḥāq al-Kindī in the 3rd/9th century, and the masterly adoption of "classical" Greek sources in the service of a distinctly Arabic musical theory by Abū Naṣr al-Fārābī and Abū ʿAlī Ibn Sīnā in the 4th/10th and early 5th/11th century, it was Ṣafīyaddīn ʿAbdalmuʾmin b. Yūsuf al-Urmawī (d. 693/1294) whose influential *Kitāb al-Adwār,*[286] a systematic compendium of musical theory, summarises and winds up the recent development. H. G. Farmer [287] called him the founder of the "Systematist school" with mathematical-physical inclination, which existed until around 900/1500. In al-Urmawī's *Kitāb al-Adwār* we encounter for the first time the division of the octave in seventeen unequal degrees as a fully developed system.[288]

In the humanities I would like to mention the important achievement by Yūsuf b. Abī Bakr as-Sakkākī (b. 555/1160, d. 626/1229) in the two interdisciplinary subjects of linguistics, *ʿilm al-maʿānī* and *ʿilm al-bayān.* The former I would translate 'grammar of style', and for the latter I borrow Wolfhart Heinrich's[289] term, 'pictorial language' (Bildersprache). ʿAbdalqāhir al-Ǧurǧānī (d. 471/1078, cf. infra p. 33) in his *Dalāʾil al-iʿǧāz* and the *Asrār al-balāġa* had created the foundation upon which as-Sakkākī elaborated his *Miftāḥ al-ʿulūm*[290] with logical systematisation into strictly defined disciplines. It seems an intermediate stage in this process

[283] *Die Geschichte der Medizingeschichtsschreibung*, in the appendix of: Walter Artelt, *Einführung in die Medizinhistorik. Ihr Wesen, ihre Arbeitsweise und ihre Hilfsmittel,* Stuttgart 1949, p. 210.

[284] v. Arslan Terzioğlu, *Mittelalterliche islamische Krankenhäuser unter Berücksichtigung der Frage nach den ältesten psychiatrischen Anstalten*, PhD thesis, Berlin 1968, p. 88 ff.

[285] v. A. Terzioğlu, op. cit. p. 97; Dieter Jetter, *Das Mailänder Ospedale Maggiore und der kreuzförmige Krankenhausgrundriß*, in: Sudhoffs Archiv (Wiesbaden) 44/1960/64-75, esp. p. 66.

[286] Facsimile editions by Ḥ. ʿA. Maḥfūẓ, Baghdad 1961 and Frankfurt: Institut für Geschichte der Arabisch-Islamischen Wissenschaften 1984; editions by H. M. ar-Raǧab, Baghdad 1980 and Ġ. ʿA. Ḫašaba, M.A. al-Ḥifnī, Cairo 1986.

[287] *The Sources of Arabian Music,* Leiden 1965, p. XXIII; Liberty Manik, *Das arabische Tonsystem im Mittelalter,* Leiden 1969, pp. 52 ff.

[288] E. Neubauer, preface to the facsimile edition, Frankfurt 1984.

[289] *Poetik, Rhetorik, Literaturkritik, Metrik und Reimlehre*, in: Grundriß der arabischen Philologie, vol. 2, Wiesbaden 1987, p. 184.

[290] v. C. Brockelmann, *Geschichte der arabischen Litteratur*, vol. 1, p. 294, suppl., vol. 1, p. 515.

had already been reached by the universal scholar Muḥammad b. ʿUmar Faḫraddīn ar-Rāzī[291] (b. 543/1149, d. 606/1209) in his *Nihāyat al-īǧāz fī dirāyat al-iʿǧāz*.[292]

In the same 7th/13th century, in which progress was made in almost all fields of Arabic-Islamic historiography, world history was treated with special interest. The monumental chronicle by ʿIzzaddīn ʿAlī b. Muḥammad Ibn al-Aṯīr[293] (b. 555/1160. d. 630/1233) was written in the first quarter of the century; under the title *al-Kāmil fī t-taʾrīḫ,* it deals with world history from genesis up to 628/1231. As far as we are aware, this is the most extensive and the most significant work of its type written since the world history by Muḥammad b. Ǧarīr aṭ-Ṭabarī (d. 310/923, supra p. 18). The author appears to be [53] extremely objective and reliable. Yet it is not correct and even unfair to call him "perhaps the only true historian of Islam in the early Middle Ages."[294] In the same spirit, ʿAlī b. Anǧab Ibn as-Sāʿī,[295] (b. 593/1197, d. 674/1276), an historian from Baghdad, wrote another chronicle of the world entitled *al-Ǧāmiʿ al-muḫtaṣar fī ʿunwān at-tawārīḫ wa-ʿuyūn as-siyar* in twenty-five volumes of which only the ninth is extant. Judged by this fragment, Ibn as-Sāʿī's book is equal to the high rank of his predecessor's.

In military technology, the ongoing necessity of defence against attacks by crusaders brought about further advances in weaponry in this century as well. The most important innovation in this field was the development of fire-arms using gunpowder. The question has not yet been solved whether the knowledge of gunpowder reached the Arabic-Islamic culture area from China or whether it was developed independently. It is however probable that its driving power was recognised and used for military purposes in the Islamic world, even if fireworks were known in China at an earlier date. As far as we know, the Arabs had used cannons since the second half of the 7th/13th century (infra V, 99); it is possible that the use of hand grenades also goes back to this century (infra V, 101 ff.).

The 8th/14th Century

Turning to the 8th/14th century, we realise that science in the Islamic world did not lose momentum in this period, in spite of all the turbulent political events. Through the loss of a substantial part of Andalusia, its scientific contributions, which had been on a high level for centuries, were diminished but did not yet cease.

In the field of astronomy the issue of Ptolemy's theory violating the principle of uniform planetary motions, which had been addressed by Ibn al-Haiṯam in the 5th/11th century and which had once more become topical in the 7th/13th century, engaged the disciples of Naṣīraddīn aṭ-Ṭūsī in the 8th/14th century. Yet the most important model aimed at restoring the principle of uniform motion was conceived, as far as we know, in Syria. Its originator was ʿAlī b. Ibrāhīm Ibn aš-Šāṭir (d. ca. 777/1375). In his models he does away with eccentricity and lets the vector (one for each planet) start from the centre of the universe while adopting Naṣīraddīn aṭ-Ṭūsī's concept of dual epicycles. Particularly important is his model of Mercury in which he makes use of a smaller epicycle than Ptolemy. He achieved excellent results in his attempt to improve the inherited models of the lunar motions. While restoring the uniform circular motion of the Moon, he corrects the glaring defect in Ptolemy's model, in which the latter had exaggerated the variations of the Moon-Earth distance.[296]

[291] ibid, vol. 1, p. 506, suppl., vol. 1, p. 920.

[292] W. Heinrichs, op. cit. p. 184.

[293] v. C. Brockelmann, op. cit., vol. 1, p. 345, suppl., vol. 1, p. 587.

[294] As is done by Francesco Gabrieli in his overview *The Arabic historiography of the Crusades*, in: *Historians of the Middle East*, ed. Bernard Lewis and P. M. Holt, London 1962, pp. 98-107, esp. p. 104.

[295] v. C. Brockelmann, op. cit. suppl., vol. 1, p. 590.

[296] v. F. Sezgin, op. cit. vol. 6, p. 36.

Recent research[297] has established that Copernicus knew the models of Ibn aš-Šāṭir and his Persian predecessors and contemporaries [54] and that their influence on him must have been profound. The points in common between Copernicus and his Arabic-Islamic predecessors, as found so far, can be summarised as follows:

1. Copernicus as well as Naṣīraddīn aṭ-Ṭūsī and Quṭbaddīn aš-Šīrāzī accept without reservation the principle that each planetary model must be based on a mechanism in which equal distances are covered by equal vectors with equal angular velocity.

2. Copernicus and his Arabic predecessors feature the mechanism of a double vector with radii equal or half the eccentricity in their planetary models, in order to emulate the function of the equant.

3. Copernicus's model of the Moon is the same as that by Ibn aš-Šāṭir; both differ substantially to Ptolemy's model in their parameters.

4. With minor alterations in the length of the vectors, Copernicus's model of Mercury is the same as Ibn aš-Šāṭir's.

5. Copernicus employs the mechanism of the double epicycles of aṭ-Ṭūsī in the Mercury model, as does Ibn aš-Šāṭir.[298]

According to the latest research, the new Arabic-Persian theories concerning the motion of the planets did not reach Copernicus via Latin translations, but through Byzantine mediation from Tabrīz und Marāġa via Trabzon and Constantinople. For instance, the two Polish scholars Sandivogius of Czechel (1430) and Adalbertus of Brudzevo (1482), in their commentaries respectively to Gerardus's *Theorica planetarum* and Peurbach's *Theoricae novae planetarum* display a fair knowledge[299] of the above mentioned planetary theories from the Arabic-Islamic culture area; therefore, by the 15th century, these theories must have been known in Cracow.

Amongst the most important astronomical achievements of that age is a type of astrolabe which had been constructed in Syria by Aḥmad b. Abī Bakr Ibn as-Sarrāǧ (d. ca. 730/1330). The instrument (infra II, 119) combines in itself the functions of a normal astrolabe and those of the universal plate as had been developed in the western part of the Islamic world. With this instrument a stage of development in the construction of astrolabes had been reached which henceforth stood unsurpassed, both in the countries of Islam and in Europe (infra, II, 84).

In mathematics, a remarkable development occurred in the 7th/13th and the 8th/14th centuries in western North Africa. It involved the knowledge and application of algebraic symbolism that remained—as far as we know now—unknown in the eastern parts of the Islamic world. It is primarily found in the works of Aḥmad b. Muḥammad Ibn al-Bannā' al-Marrākušī[300] (b. 654/1256, d. 721/1321) and his grand-disciple, Abu l-ʿAbbās Aḥmad b. Ḥasan Ibn Qunfuḏ[301] (b. 731/1331 or more likely 741/1340, d. 809/1406 or 810/1407). That Ibn al-Bannā', according to his book *Rafʿ al-ḥiǧāb*,[302] had [55] the mathematicians Ibn Munʿim (Aḥmad b. Muḥammad

[297] For example: E. S. Kennedy, *Late medieval planetary theory,* in: Isis (Baltimore) 57/1966/365-378, esp. p. 377: idem, *Planetary theory in the medieval Near East and its transmission to Europe*, in: Oriente e Occidente nel medioevo. Convegno internazionale 9-15 aprile 1969, Rome 1971 (Accademia Nazionale dei Lincei), pp. 595-604, esp. pp. 600-602; F. Sezgin, op. cit. vol. 6, p. 56.

[298] v. F. Sezgin, op. cit. vol. 6, pp. 55-56

[299] v. G. Rosiøksa, *Naṣīr al-Dīn al-Ṭūsī and Ibn al-Shāṭir in Cracow?* in: Isis (Washington, D.C.) 65/1974/239-243; F. Sezgin, op. cit. vol. 6, p. 56.

[300] C. Brockelmann, op. cit. vol. 2, p. 255, suppl. vol. 2, pp 363-364; Juan Vernet in: *Dictionary of Scientific Biography*, vol. 1, New York 1970, pp.437-438.

[301] v. H. P. J. Renaud, *Sur un passage d'Ibn Khaldûn relatif à l'histoire des mathématiques*, in: Hespéris (Paris) 31/1944/35-47 (reprint in: Islamic Mathematics and Astronomy, vol. 44, pp. 191-203); F. Sezgin, op. cit. vol. 5, p. 62.

[302] Ed. by M. Aballagh, Paris 1988; cf. idem, *Les fondements des mathématiques à travers le Rafʿ al-Hijāb d'Ibn al-Bannā (1256-1321),* in: Histoire des mathématiques arabes. Actes du premier colloque international sur l'histoire

al-ʿAbdarī[303]) and al-Aḥdab as his predecessors in the knowledge of algebraic symbolism was mentioned already by the well-known historian ʿAbdarraḥmān Ibn Ḫaldūn (d. 808/1406).[304] This is corroborated by the treatises *Fiqh al-ḥisāb* by Ibn Munʿim and *Rafʿ al-ḥiǧāb* by Ibn al-Bannāʾ, which were discovered in the last decade of the 20th century. Ibn al-Bannāʾ excelled with further important contributions, among them an approximation formula for the extraction of the square root.[305] For this matter he distinguishes between two cases, viz. "whether, after $\sqrt{a^2+r} \approx a$ has been found, r turns out to be smaller or equal, or bigger than a. If $r \leq a$, one should equate $\sqrt{a^2+r} = a + \frac{r}{2a}$; on the other hand, if $r > a$, for better approximation one should equate $\sqrt{a^2+r} = a + \frac{r}{2a+1}$.[306] In formulating this, Ibn al-Bannāʾ no doubt relied heavily on his predecessor Muḥammad b. ʿAbdallāh al-Ḥaṣṣār (7th/13th c.).[307] It is possible that the method for the extraction of the square root by the Spanish mathematician Juan de Ortega (d. ca. 1568) is also connected with this.[308]

From the fields of physics and technology, a remarkable clock should be mentioned, constructed by the above-mentioned Ibn aš-Šāṭir, and described by the historian Ḫalīl b. Aibak aṣ-Ṣafadī (d. 764/1363). Aṣ-Ṣafadī visited Ibn aš-Šāṭir in Damascus to see this device invented by the latter and described it in the following words:[309] It "was positioned vertically against a wall, … had the shape of a bow (*qanṭara*) and measured approximately 3/4 ells … it ran day and night, without sand and without water and followed the motion of the celestial sphere, according to a special regulation,… indicating both equal and temporal hours." This brief description leads us to the assumption that it might have been a weight driven mechanical clock.

In the 8th/14th century the Arabic-Islamic world area proved to be as creative as ever. Hence, in the field of optics, this century produced one of the most important scholars of the time. We are referring to Kamāladdīn Muḥammad b. al-Ḥasan al-Fārisī (b. 665/1267, d. 718/1318), otherwise known [56] as an outstanding physicist and mathematician. He wrote a monumental commentary, *Tanqīḥ al-Manāẓir,* on the "Optics" of Ibn al-Haiṯam (supra p. 29 ff.), which has not yet been exhaustively studied; in it we find an epochal explanation of the

des mathématiques arabes, Alger 1-3 décembre 1986, Alger 1988, pp. 133-156, esp. pp. 140-142.

[303] v. A. Djebbar, *L'analyse combinatoire au Maghreb: l'exemple d'Ibn Munʿim (XIIe-XIIIe s.)*, Orsay 1985 (Publications mathématiques d'Orsay no. 85-01). The identification of this mathematician as Ibn ʿAbdalmunʿim (active in Sicily at the court of Roger II), as suggested by H. Suter and H. P. J. Renaud and adopted in my *Geschichte des arabischen Schrifttums*, vol. 5, p. 62, is not correct.

[304] v. *Ibn Khaldûn, The Muqaddimah. An introduction to history*, translated from the Arabic by Franz Rosenthal, vol. 3, New York 1958, p. 123; F. Sezgin, op. cit. vol. 5, p. 62.

[305] Ibn al-Bannāʾ al-Marrākušī, *Talḫīṣ aʿmāl al-ḥisāb*, ed. by M. Suwīsī, Tunis 1969, pp. 63-66; French transl. Aristide Marre, *Le Talkhys d'Ibn Albannâ, traduit pour la première fois…,* in: Atti dell' Accademia Pontificia de'Nuovi Lincei (Rome) 17/1864/289-319, esp. pp. 311-313 (reprint in: Islamic Mathematics and Astronomy, vol. 44, pp. 1-31, esp. pp. 23-25).

[306] M. Cantor, *Vorlesungen über Geschichte der Mathematik*, op. cit. vol. 1, p. 808.

[307] v. Heinrich Suter, *Das Rechenbuch des Abû Zakarîjâ el-Ḥaṣṣâr*, in: Bibliotheca mathematica (Leipzig) 3rd series, 2/1901/12-40, esp. pp. 37-39 (reprint in: Islamic Mathematics and Astronomy, vol. 77, pp. 322-360, esp. pp. 357-359).

[308] v. J. Vernet in: *Dictionary of Scientific Biography*, vol. 1, New York 1970, p. 437.

[309] The quotation from the as yet unpublished 20th vol. of the *Kitāb al-Wāfī bi-l-wafayāt* by *aṣ-Ṣafadī* was freely rendered by E. Wiedemann from the French version of *Description de Damas* by Henri Sauvaire (Paris 1894-1896, vol. 2, pp. 207-208; reprint in: Islamic Geography, vol. 81, pp. 277-278), (v. *Über die Uhren im Bereich der islamischen Kultur* by Eilhard Wiedemann in collaboration with Fritz Hauser in: Nova Acta. Abhandlungen der Kaiserlich Leopoldinisch-Carolinischen Deutschen Akademie der Naturforscher, vol. 100,5, Halle 1905, p. 19, reprint in: E. Wiedemann, *Gesammelte Schriften* vol. 3, pp. 1211-1482, esp. p. 1229, and in: Natural Sciences in Islam, vol. 41, pp. 21-292, esp. p. 39).

phenomenon of the rainbow the like of which his predecessors Ibn al-Haiṯam and Ibn Sīnā in the 5th/11th century, despite their attempts, had not been able to give (infra III, 166 ff.). In Kamāladdīn al-Fārisī's opinion, the perception of a rainbow is caused by the optical behaviour of fine transparent spherical drops close to each other in the air, through double refraction and single or double reflection of the sunlight as it enters into and comes out of the individual drop. Kamāladdīn came to this conclusion after a series of systematic experiments conducted with a spherical ball made of glass or rock-crystal (infra III, 166).

One of the most significant results of Kamāladdīn's research in the field of optics known so far is his theory of the image seen in the pupil. Matthias Schramm[310] first noticed that Kamāladdīn "rejected Galen's explanation as incompatible with the principles of optics" and investigated the true state of affairs by means of controlled experiments. To this end he used a mutton eye. Doing so, "he was the first to establish incontestably the reflection from the outer surface of the lens and he gave an excellent explanation in terms of his theory." Schramm points out that the results achieved by Kamāladdīn are the same "as those reached by Johannes Evangelista Purkynje again as late as 1823."

With regards to the history of reception of Arabic-Islamic sciences in the West, it is of particular significance that Kamāladdīn's explanation of the phenomenon of the rainbow appears again with a few minor alterations in the treatise *De iride et radialibus impressionibus* by Dietrich of Freiberg (Theodoricus Teutonicus), a little known Dominican monk in the first decade of the 14th century. In ignorance of—or perhaps ignoring—the process of reception and assimilation of Arabic-Islamic sciences in the West the physicist G. Hellmann in the year 1902 described the presentation of the rainbow-theory in Dietrich of Freiberg's book as "the greatest achievement made in the Occident in this matter during the Middle Ages".[311]

Not long after this rampant review of Dietrich's treatise, Kamāladdīn's work became known in the circles of E. Wiedemann's disciples and the question of a possible connection between Kamāladdīn and Dietrich was considered. This, of course, was at a time when the channels of the reception- and assimilation-process and its consequences were not understood as well as they are today. One of the explanations—proposed by Otto Werner[312] in his study on Leonardo da Vinci's physics, from the year 1910—is of general interest beyond the specific matter in question. It occured to Werner that Kamāladdīn's book must have been known in the Occident and was even used by Leonardo da Vinci. He also saw a close connection between Kamāladdīn and Dietrich (infra III, 169 ff.). I myself have no doubt that Dietrich of Freiberg must have become acquainted with Kamāladdīn's achievements either directly through his book or during a stay in the [57] Islamic world. The common features in fundamentals as well as details are so numerous that they cannot possibly be independent achievements. The first half of the 14th century is indeed to be characterised as a period when the sciences of the Arabic-Islamic world found their way quickly from Northern Africa to France and Italy, and from Syria, Anatolia and Persia directly or via Constantinople to Italy and Central Europe. Mediators from the clerical orders, particularly the Dominicans, proved particularly able in this process of reception and earned great merit.

[310] *Zur Entwicklung der physiologischen Optik in der arabischen Literatur*, in: Sudhoffs Archiv für Geschichte der Medizin und der Naturwissenschaften (Wiesbaden) 43/1959/289-316, esp. pp. 311-316.

[311] *Meteorologische Optik* 1000-1836, Berlin 1902 (= Neudrucke von Schriften und Karten über Meteorologie und Erdmagnetismus, Bd. 14), p. 8.

[312] *Zur Physik Leonardo da Vincis*, PhD thesis, Erlangen 1910, p. 111.

In the field of medicine, a clear insight into the nature of infections, amongst other achievements, calls for our attention. Several related treatises were written in Islamic Spain following the devastating plague that had infested the countries of the western Mediterranean in 749/1348. The following titles are amongst them: *Muqniʿat as-sāʾil ʿan al-maraḍ al-hāʾil* by Muḥammad b. ʿAbdallāh Ibn al-Ḫaṭīb (b. 713/1313, d. 776/1374),[313] *Taḥṣīl al-ġaraḍ al-qāṣid fī tafṣīl al-maraḍ al-wāfid* by Aḥmad b. ʿAlī Ibn Ḫātima (d. ca. 770/1369)[314] and *Taḥqīq an-nabaʾ ʿan amr al-wabaʾ* by Muḥammad b. ʿAlī aš-Šaqūrī (b. 727/1327).[315] The first two works, surviving intact, relate their authors' experiences with the effects of contagion. The medical world was made aware of the importance of Ibn al-Ḫaṭīb's treatise by Marcus Joseph Müller as early as in 1863 through an edition of the Arabic text, accompanied by its German translation. According to Max Meyerhof,[316] the Arabic writings on the plague were far superior to those written in Europe between the 14th and 16th centuries. A few sentences from Ibn al-Ḫaṭīb may testify to this:

"The existence of contagion is established as a fact by experience, research, perception, autopsy and authenticated information, and those are the instruments of proof. Everybody who has seen the thing itself or gathered information about it knows that most of those who come into contact with people afflicted with the disease die and those with whom this is not the case remain healthy; furthermore that this disease occurs in a house or in a quarter because of a garment or a receptacle so that even an earring can cause the death of a person donning it and thus brings devastation upon the entire house; moreover that in one city the disease occurs in a single house and then blazes up in those individuals who have contact with the sick person, then in the neighbours and relatives and especially among those who [58] pay visits to the house of the sick person, so that the breach becomes wider and wider; furthermore that the population of sea ports enjoys perfect health until an infected man arrives from another country where the plague prevails notoriously and the date of the outbreak of the disease in the town coincides with the date of his arrival."[317]

We encounter further evidence on the progress in medical science of those days in the Arabic-Islamic culture area in the comprehensive ophthalmologic textbook by Ṣadaqa b. Ibrāhīm al-Miṣrī aš-Šāḏilī (2nd half 8th/14th c.) entitled *al-ʿUmda al-kuḥlīya fi l-amrāḍ al-baṣarīya.*[318] In the sixth chapter of the first part concerning "the dissimilarity of animals' eyes and the human eye and the peculiar features of the latter,"[319] J. Hirschberg found "the nucleus

[313] v. C. Brockelmann, *Geschichte der arabischen Litteratur*, vol. 2, p. 262, suppl. vol. 2, p. 372; M. J. Müller, *Ibnulkhatîbs Bericht über die Pest*, in: Sitzungsberichte der Königlichen Bayerischen Akademie der Wissenschaften (München). Philosophisch-philologische Klasse 2/1863/1-34 (reprint in: Islamic Medicine, vol. 93, pp. 37-70).

[314] v. C. Brockelmann, op. cit. vol. 2, p. 259, suppl. vol. 2, p. 369; a selection edited by M. al-ʿArabī al-Ḫaṭṭābī, *aṭ-Ṭibb wa-l-aṭibbāʾ fi l-Andalus al-islāmīya*, Beirut 1988, vol. 2, p. 161-186; German transl. by Taha Dinānah, *Die Schrift von Abī Ǧaʿfar Aḥmed ibn ʿAlī ibn Moḥammed ibn ʿAlī ibn Ḫātimah aus Almeriah über die Pest*, in: Archiv für Geschichte der Medizin (Leipzig) 19/1927/27-81 (reprint in: Islamic Medicine, vol. 92, p. 239-293); Melchor M. Antuña, *Abenjátima de Almería y su tratado de la peste*, in: Religion y Cultura (El Escorial/ Madrid) 1,4/1928/68-90 (reprint in: Islamic Medicine, vol. 92, pp. 294-316).

[315] v. Henri-Paul-Joseph Renaud, *Un médecin du royaume de Grenade. Muḥammad aš-Šaqūrī*, in: Hespéris (Paris) 33/1946/31-64 (reprint in: Islamic Medicine, vol. 92, pp. 181-214).

[316] *Science and medicine*, in: The Legacy of Islam, ed. Th. Arnold, London 1931, pp. 311-355, esp. pp. 340-341 (reprint in: Islamic Medicine, vol. 96, pp. 99-147, esp. pp. 132-133); v. also Gustave E. von Grunebaum, *Medieval Islam. A study in cultural orientation,* 2nd ed., Chicago 1961, pp. 335-336.

[317] Translation by M. J. Müller, op. cit., pp. 18-19 (reprint pp. 54-55), with slight modifications

[318] v. C. Brockelmann, op. cit. vol. 2, p. 137, suppl. vol. 2, p. 170.

[319] *Geschichte der Augenheilkunde*, vol. 2: *Geschichte*

of comparative anatomy and physiology of the visual organ" which was only to be found in scientific form in the textbooks of ophthalmology in the second half of the 19th century (infra IV, 17).

Finally from the field of medicine we should mention the Persian *Tanksūqnāma-i Īlḫānī dar funūn-i ʿulūm-i ḫitāʾī*, written at the beginning of the 8th/14th century and dealing with "Chinese sciences". Its author was the Īlḫānid grand vizier Rašīdaddīn Faḍlallāh b. ʿImādaddaula (b. ca. 645/1247, d. 718/1318).[320] The book contains "not only an adequate account of lost books, but also provides an extremely arresting picture of this great vizier's vast horizon and interests … According to the characterisation given in the introduction of the four predominantly medico-pharmaceutical books summarised in the 'Tanksūqnāme', the extant book turns out to be a Persian translation of a partly rhymed anatomical work which, after its supposed Chinese author, is here given the title 'Wang Shu-ho'. It is, however, not the classical Mo-ching by the famous physician Wang Shu-ho (265-317 CE), but a work called Mo-chüeh, which deals with the modalities of pulse observations and the anatomy of the most important human organs. It originated in northern China at the time of the Kin-dynasty (1122-1234). With its numerous illustrations which undoubtedly go back to a Chinese original, the alleged 'Wang Shu-ho' is the oldest authentic example of a 'graphic Chinese anatomy' in the Near East, indeed in the entire western world." The third book deals partly with drugs of ancient China and partly with other pharmaceuticals in the form of a drug-manual. To it Rašīdaddīn Faḍlallāh, who was a physician by profession, supplied an appendix with "tables of Chinese drugs unknown to the Greeks, with a precise description of their usage and efficacy in the form of a book." [321]

[59] In the field of geography, interesting evidence survives from the 8th/14th century to demonstrate that the mathematical representation of the surface of the Earth and its cartographic depiction, fostered in the Arabic-Islamic world in the preceding centuries, reached a new level of quality. From the western part of the Islamic world we know the important table of coordinates, comprising 97 localities, by the astronomer and mathematician Muḥammad b. Ibrāhīm Ibn ar-Raqqām (d. 715/1315) of Murcia. The table shows that the fundamental correction of the longitudes, carried out in Andalusia and the Maghrib, had by that time been extended to a larger part of the oikoumene and that the length of the grand axis of the Mediterranean has been reduced to 44° and, consequently, is only 2° too long compared to modern values. Of course, the correction was not restricted to the length of the grand axis. It is apparent in the distances between the western border of the oikoumene and the places east of Baghdad as well. Other extant tables with significant corrections to the longitudes allow the assumption that these tables enjoyed a wide dissemination. One such table was discovered in Latin translation by the Spanish Arabist I. Millás Vallicrosa in the middle of the 20th century and is of particular interest in this context. It was most probably composed in the east Andalusian town of Tortosa (Ṭurṭūša), and it is surprising in that the reduction of longitudes has now been implemented for Baghdad as the prime meridian, even for the places in the west. This table has also reached us in a

der Augenheilkunde im Mittelalter, Leipzig 1908 (= Graefe-Saemisch, *Handbuch der gesamten Augenheilkunde*, vol.13), pp. 156-159.

[320] The only surviving manuscript dating from Rašīdaddīn's time is kept in Istanbul, Ayasofya 3596 (264 ff., 713 H.), facsimile edition by Muǧtabā Mīnuwī, Tehran 1972; Karl Jahn, *The still missing works of Rashīd al-Dīn*, in: Central Asiatic Journal (Wiesbaden) 9/1964/113-122; idem, *Wissenschaftliche Kontakte zwischen Iran und China in der Mongolenzeit*, in: Anzeiger der Philologisch-historischen Klasse der Österreichischen Akademie der Wissenschaften (Wien) 106/1969/200-211.

[321] K. Jahn, *Wissenschaftliche Kontakte zwischen Iran und China in der Mongolenzeit*, op. cit., pp. 201-203.

Portuguese version. It contains the coordinates of 31 places in Spain, Western Europe and the western Mediterranean. Although it is not free from spelling errors and misreadings, it provides important evidence of the great advances made in Western Europe not least with regard to Arab-Spanish cartography. London can be taken as an example. According to this table the coordinates for London, reckoned from Baghdad, are Long 42°, Lat 48° (modern values Long 44°26' and Lat 51°30'). The difference in longitude between London and Baghdad (Babylon) in Ptolemy shows an error of 18°, with the Ma'mūn geographers it was still 9°, whereas in this table the deviation is merely 2°26'. Further examples can be found in my *Geschichte des arabischen Schrifttums;*[322] here I would like to emphasise that these corrections, essential for the history of mathematical geography, have so far remained completely unknown and thus did not play any part in the discussion on the origin of the new maps which emerged in Europe from the turn of the 13th to the 14th century.

In the process of the mathematical survey of the areas to the west of Baghdad, Asia Minor, which was under Byzantine rule, and the Aegean remained for a long time outside the reach of Arabic-Islamic geographers and astronomers. As far as we know now, this situation appears to have started to change from the end of the 6th/12th century. Surprisingly accurate and detailed maps of those areas and of the Black Sea begin to appear in Europe almost suddenly from the turn of the 13th to the 14th century; for example Giovanni da Carignano's map.[323] These maps can only be regarded as the result of astronomical observations and geodetic measurements made on location, over a long period of time and with governmental support. We know of some sparse coordinates of Asia Minor which seem to have been determined under Islamic rule in the 7th/13th century at the latest. Yet only an [60] early Ottoman table, probably from the first half of the 8th/14th century, provides us with the coordinates of 151 localities, an eighth of which are in Asia Minor; this table is found in the treatise on astrolabes by one ʿAbdalḥalīm b. Sulaimān aṭ-Ṭūqātī.[324] The table documents the early participation of Ottoman scholars in the elaboration of the graticule, at least in Anatolia. It also justifies the assumption that by that time fairly accurate results were achieved in the mathematical survey of Asia Minor. The same accuracy is found also in the table's coordinates for the Mediterranean. We observe, for instance, that the longitudinal difference Rome—Constantinople and Rome—Alexandria deviate surprisingly little from the modern values. Regarding the west-east and north-south dimensions of Anatolia we may refer to aṭ-Ṭūqāṭī's values for Constantinople and for Aḫlāṭ, the easternmost place in Anatolia. The longitudinal difference differs only by 1°29' from the modern value, and the latitude even by a mere 2'. In order to give the reader an adequate idea of the significance of these values determined in the 8th/14th century, we may mention that the actual longitudinal and latitudinal difference between these cities was established only in the 20th century.

Arabic and Persian writings of the first half of the 8th/14th century yield so many relevant documents and data that we must assume that many local cartographers and geographers took for granted that in the making of accurate maps precise coordinates in longitude and latitude were indispensable. One of the most important examples known to me at this time involves the universal scholar Rašīdaddīn, whose work on Chinese medicine was mentioned above. His secretary, who was responsible for bringing the master's books in the desired form, states that Rašīdaddīn's geographical work described the seven climata, the parts of the known world, the seas and oceans, mountains, valleys etc. along with the degrees of longitudes and latitudes

[322] v. F. Sezgin, op. cit vol. 10, p. 167.
[323] v. ibid, vol. 10, pp. 332-337.
[324] v. F. Sezgin, op. cit. vol. 10, pp. 180-181.

found in the corresponding books, that the data were verified and that information was gathered from experts on the various countries in order that the data did not deviate from reality. We also learn that due to the size of the maps an extraordinarily large format was chosen for the book, since the maps "following the methods of the experts" were to be made "as clear and as comprehensible as possible" and "the places were also to be drawn onto the map as precisely as possible."[325]

It is a pity that the cartographic material surviving from this period in the original languages—Arabic and Persian—is confined to a sketchy map covering the area from Anatolia to Central Asia included in the book *Nuzhat al-qulūb* by the Persian geographer and historian Ḥamdallāh al-Mustaufī (d. ca. 740/1340). The map[326] stretches in length from 63° to 112° and in latitude from 16° to 45° north of the equator. The names of about 120 localities are placed within an orthogonal graticule. The user can read the coordinates from scales framing the map. The significance of this map lies in the fact that the graticule is based on the integrated west-east longitudes—according to the above mentioned (p. 43 ff.) astronomers in Marāġa—reckoned from the prime meridian at 28°30' west of Toledo. What's more, the longitudes (leaving aside obvious slips), approach modern values up to 3° or 4°.

[61] One of the important contributions by the Arabic-Islamic world in the field of geography is the extensive travelogue by Muḥammad b. ʿAbdallāh Ibn Baṭṭūṭa (b. 703/1304, d. 770/1369), who hailed from Tangiers in Morocco. Aged 22 he left his native town bound for Mecca, visited Alexandria and Cairo, went up the Nile to Syene (now Aswan), from there to Syria and Palestine, crossed Arabia up to Mecca, turned towards East Africa and reached Mozambique, visited Asia Minor and Byzantium, southern Russia (up to the 55° northern Lat.), Central Asia, India, the Malay peninsula and China, made extended sojourns and visited certain places repeatedly. After 24 years he returned to Tangiers. A second journey took him to Andalusia, a third to Northern Africa. With his travels lasting all in all 27 years, Ibn Baṭṭūṭa was, in the words of Richard Hennig[327] "in fact the greatest world traveller in all Antiquity and Middle Ages." Through Ibn Baṭṭūṭa's gift for keen observation and his highly developed sense for matters of historical geography, anthropology and cultural history, his extensive travelogue became an invaluable document in the history of geography (cf. infra III, 8).

Historiography in the 8th/14th century brought forth numerous world chronicles, municipal and local histories, large-scale biographical dictionaries covering either the entire Islamic period or merely the present century, and various other writings; I shall confine myself to mentioning one world history and three encyclopaedias. The world history in question is the monumental *Ǧāmiʿ at-tawārīḫ* by the above mentioned universal scholar Rašīdaddīn Faḍlallāh (d. 718/1318, infra, p. 157 ff.). It was begun in the year 700/1301 by commission of the Īlḫān Ġāzān as a history of the Mongols and the Turks; a few years later it was extended into a universal history according to the desire of Ölǧeitü, the brother and successor of Ġāzān, and was completed in 710/1311. The first volume deals with the history of Čengīz Ḫān and his successors in East and West Asia, as well as with the Turkish and Mongol tribes. The second volume deals at length with the history of the nations that came into contact with the Mongols. It begins with the pre-Islamic Iranian empires, followed by the history of the Muslim prophet and caliphs, Islamic dynasties in Persia, the

[325] v. Étienne Quatremère, *Raschid-eldin. Histoire des Mongols de la Perse*, Paris 1836 (reprint Amsterdam 1968), introduction pp. CXLVIII, CLX; F. Sezgin, op. cit. vol. 10, p. 314.

[326] v. F. Sezgin, op. cit. vol. 10, pp. 200-210; vol. 12, No. 16a.

[327] *Terrae incognitae*, vol. 3, Leiden 1953, p. 213.

Oghuzs, Turks, Chinese, Jews and Franks, and lastly India, with emphasis on Buddhism. The third volume devoted to geography is lost.

Rašīdaddīn's book was of course not the first universal history produced in the Arabic-Islamic culture area on the history and culture of foreign nations, together with those in the Islamic world. It had numerous precursors like *Murūǧ aḏ-ḏahab*, *Aḫbār az-zamān* and *Kitāb al-ʿAǧāʾib* by ʿAlī b. al-Ḥusain al-Masʿūdī (d. 345/956 or 346),[328] *al-ʿUnwān al-kāmil* by Maḥbūb b. Qusṭanṭīn al-Manbiǧī (ca. 350/961),[329] *Tawārīḫ sinī mulūk al-arḍ wa-l-anbiyāʾ* by Ḥamza b. al-Ḥasan al-Iṣfahānī (d. before 360/970),[330] *al-Āṯār al-bāqiya min al-qurūn al-ḫāliya* (on the eras and festival calendars of the Greeks, Romans, Persians, the inhabitants of Soghdia, Ḫwārizm and Ḥarrān, the Copts, other Christians and the Jews) and *Taḥqīq mā li-l-Hind* by Abu r-Raiḥān Muḥammad b. Aḥmad al-Bīrūnī (d. 440/1048)[331] and many more written before, not to mention those after Rašīdaddīn.[332] [62] However, in his work on the Mongols and nations that came in contact with them, Rašīdaddīn wanted to take a "new path" by "availing himself of the original historical sources of the respective nations themselves."[333] This he seems to have accomplished, at least in the Mongol history. The air of sobriety and objectivity pervading the whole work reminds us of al-Bīrūnī's Chronicle (*al-Āṯār al-bāqiya*) and his book on India (*Taḥqīq mā li-l-Hind*) mentioned above. The latter in particular has earned its author a unique position in cultural history, as the book not only leaned upon local sources, but was written on the basis of observations made by the author himself during a long stay in India and of insights gained in direct contact with the people.

The earliest large scale encyclopaedias also appeared in the first half of the 8th/14th century. The initial one is entitled *Manāhiǧ al-fikar wa-mabāhiǧ al-ʿibar*[334] and was written by Ǧamāladdīn Muḥammad b. Ibrāhīm al-Kutubī al-Waṭwāṭ (b. 632/1235, d. 718/1318).[335] The work comprises the areas heaven and earth, animals and plants, and by its character testifies to the predominantly literary inclinations of its author. Inspired by this work, the Egyptian historian Šihābaddīn Aḥmad b. ʿAbdalwahhāb an-Nuwairī (b. 677/1279, d. 732/1332) wrote his encyclopaedia *Nihāyat al-arab fī funūn al-adab*[336], conceived in 30 volumes with the aim of collecting the knowledge expected of a cultivated secretary or government official. The inclusion of history as a separate, new topic offered the opportunity to cover all human affairs and achievements in the book; but an-Nuwairī not only increased the number of topics (funūn) compared to his predecessor, he also made a new arrangement of the material: 1. heaven and earth, 2. man, 3. animals, 4. plants, 5. history. This encyclopaedia leads us to many traces of sources otherwise lost and it is one of the best textbooks on the history of that time.

The third encyclopaedia which appeared in this century is entitled *Masālik al-abṣār fī mamālik al-amṣār* and was written by Šihābaddīn Aḥmad b. Yaḥyā al-ʿUmarī (b.

[328] v. F. Sezgin, op. cit. vol. 1, pp. 332-336.

[329] Ibid, vol. 1, p. 338.

[330] Ibid, vol. 1, p. 336.

[331] Ibid, vol. 6, pp. 270-271.

[332] v. Franz Rosenthal, *A history of Muslim historiography*, Leiden 1952, pp. 114-130.

[333] Karl Jahn, *Die Erweiterung unseres Geschichtsbildes durch Rašīd al-Dīn*, in: Anzeiger der Österreichischen Akademie der Wissenschaften, Philologisch-historische Klasse (Wien), 107/1970 (1971)/139-149, esp. 143.

[334] Facsimile edition in 2 vols., Frankfurt, Institut für Geschichte der Arabisch-Islamischen Wissenschaften 1990.

[335] v. C. Brockelmann, op. cit. vol. 2, pp. 54-55, suppl. vol. 2, pp. 53-54; F. Sezgin, preface to the facsimile edition.

[336] v. C. Brockelmann, op. cit. vol. 2, pp. 139-140, suppl.-vol. 2, pp. 173-174; I. Kratschkowsky in: Encyclopaedie des Islām, vol. 3, Leiden 1936, pp. 1045-1047; Mounira Chapoutot-Remadi in: Encyclopaedia of Islām. New edition, vol. 8, Leiden 1995, pp. 156-160

700/1301, d. 749/1349).[337] It was composed between 741/1341 and 749/1349 when its author was head of the chancery in Damascus. It is possible that Ibn Faḍlallāh conceived the idea of creating his own encyclopaedia during his sojourn in Cairo, where he stayed until 740/1339. There he could have become acquainted with an-Nuwairī's work which already enjoyed tremendous popularity. Yet the book of Ibn Faḍlallāh is different from that of his predecessor in its aim, structure, and content. Perhaps the *Masālik al-abṣār* could be labelled an anthropogeographical encyclopaedia. Its title ("Routes toward Insight into the Capital Empires") is also in accord with this. The first four of its twenty-seven volumes are devoted to geography. [63] All the other volumes deal with the intellectual achievements of humankind and its environment. Even though the entire work leaves the impression of a not yet fully fledged concept of an encyclopaedia, with its rich contents, it is one of the most significant literary achievements of the century, often going back to otherwise lost sources, and at the same time relating state of the art contemporary knowledge. In my opinion, the world map, the three sectional maps and the abundant text fragments from the Ma'mūn geography contained therein belong to the most important known documents in the history of geography and cartography.[338]

After the encyclopaedias of the 8th/14th century, we now turn to a work that reflects the maturity of the period, being one of the greatest intellectual accomplishments of Arab-Islamic culture. It is the *Muqaddima*, the "Introduction" to history by ʿAbdarraḥmān b. Muḥammad Ibn Ḫaldūn (b. 732/1332, d. 808/1406).[339] The *Muqaddima,* written after the world chronicle *al-ʿIbar wa-dīwān al-mubtada' wa-l-ḫabar* dedicated to the Merinid ruler Abū Fāris ʿAbdalʿazīz (reign. 768/1366-774/1372), was completed in the year 779/1377. It drew the attention of Arabists and non-Arabists after the two scholars Antoine-Isaac Silvestre de Sacy[340] and Joseph von Hammer-Purgstall[341] had drawn attention to its contents at the beginning of the 19th century. Particular interest was aroused in scholarly circles by Hammer-Purgstall referring to Ibn Ḫaldūn as the "Arabic Montesquieu".[342] In his work known as *Prolegomena* in the west, important fundamental ideas were discovered and commented upon with admiration: ideas concerning sociology, philosophy of history, economics, geography, anthropology, psychology and the history of sciences. Quite frequently Ibn Ḫaldūn is seen as the founder of sociology and the philosophy of history. Others find the basic problems of all branches of science addressed in his work. Regarding its treatment of the science of politics, the *Muqaddima* was compared to *Il principe* by Niccolò Machiavelli (d. 1527).[343]

In the field of military technology, the development of firearms, initiated in the preceding

[337] C. Brockelmann, op. cit. vol. 2, p. 141, suppl. vol. 2, pp. 175-176; for further bibliographical data v. the preface to the facsimile edition.

[338] Facsimile edition in 27 volumes, Frankfurt, Institute for the History of Arabic-Islamic Sciences 1988-1989, indices in three volumes, ibid, 2001.

[339] Born in Tunis, he held high offices in Fez, Granada, Tlemcen, Tunis and Cairo, where he died, v. C. Brockelmann, op. cit. vol. 2, pp. 242-245, suppl. vol. 2, pp. 342-344; Alfred Bel in: Enzyklopaedie des Islām, vol. 27, Leiden and Leipzig 1927, pp. 419-421; G. Sarton, *Introduction to the history of science*, vol. 3, part 2, pp. 1767-1779; M. Talbi in: Encyclopaedia of Islam. New edition, vol. 3, Leiden and London 1971, pp. 825-831; Franz Rosenthal in: *Dictionary of Scientific Biography*, vol. 7, New York 1973, pp. 320-323

[340] v. his article *Ibn-Khaldoun*, in: Biographie universelle (Michaud) vol. 21, Paris, shortly after 1811, pp. 268-270.

[341] *Sur l'introduction à la connaissance de l'histoire. Célèbre ouvrage arabe d'Ibn Khaldoun*, in: Journal Asiatique (Paris) 1/1822/267-278.

[342] *Über den Verfall des Islams nach den ersten drei Jahrhunderten der Hidschrat*, Wien 1812 (not seen), v. G. Sarton, op. cit. vol. 3, part 2, p. 1776.

[343] v. Allan H. Gilbert, *Machiavelli's "Prince" and its forerunners*, Durham, N. C. 1938, p. 280 (not seen, v. G. Sarton, op. cit. pp. 1769,1775).

century, continued through the 8th/14th century. In an anonymous book on the technology of warfare, which is kept in the Asiatic Museum (Institut Narodov Azii) in Petersburg[344] and probably belongs to the first half of the 8th/14th century, a combined thrusting weapon and hand gun is described which consists of a hollowed out lance that also serves for shooting a missile driven by the force of gunpowder. [64] It seems that this type of hand gun reached Europe at the turn of the 8th/14th to the 9th/15th century (infra V, 133). Besides this, in the same St. Petersburg manuscript we find the illustration of a firearm which appears to be a kind of mortar; however, the illustration does not match the description in the text. It is possible that the illustration depicts yet another mortar-like weapon, different from the one in the description (ibid).

The earliest mention of a steel crossbow known so far dates back to the first half of the 8th/14th c. as well (infra V, 96). In all probability, Europe became acquainted with this as early as at the turn of the 8th/14th to the 9th/15th century. The earliest reference to the use of steel crossbows in Europe dates from the year 1435.[345]

The 9th/15th century

According to the provisional state of our knowledge, scientific activities were still intact in all fields and throughout the Islamic world in the 9th/15th century. The new cultural centres emerging in the Seljuk dominions founded since the 6th/12th century in Anatolia and in the Ottoman empire which began to expand from the beginning of the 8th/14th century contributed substantially to this. Of the numerous works surviving from that century and kept in libraries as manuscripts, only a small fraction has been published yet and even fewer have been studied. In this connection, we may point to the outstanding activities in the field of astronomy and mathematics during the first half of the century in Transoxania which are connected with the name of the statesman Uluġ Beg Muḥammad Tūrġāy (b. 796/1394, d. 853/1449). He turned Samarqand into what his grandfather Tīmūr had envisioned, i.e. the centre of Islamic civilisation of his times.[346] This prince who was filled with enthusiasm for the sciences in his youth had received a sound education in theology, history, poetry and other subjects; long before his ascent to power he invited many famous scholars to Samarqand, including Ġiyāṯaddīn Ǧamšīd b. Masʿūd al-Kāšī (d. 832/1429) and Qāḍīzāde Rūmī (d. ca. 840/1436). Of the institutions which he founded there, the most important was without doubt the monumental observatory—inspired by its forerunner in Marāġa—where he himself worked alongside the scholars mentioned above. The younger scholar ʿAlāʾaddīn ʿAlī b. Muḥammad al-Qūšǧī (d. 879/1474) also contributed to the construction and the further development of the observatory in Samarqand. Judged by the extant remains, the radius of the scale, built according to the principle of the Faḫrī sextant in Rayy (4th/10th century, infra II, 25), measured about 30 m. Most of the results of the observations made at the observatory[347] were incorporated into the book of tables, *Zīǧ-i Sulṭānī*, composed by Uluġ Beg himself. In Europe John Graves draw attention to this fact as early as in the middle of the 17th century.[348]

[344] Current accession number C 686 with the title *al-Maḫzūn fī ǧamīʿ al-funūn* (infra V, 100).

[345] v. G. Köhler, *Die Entwickelung des Kriegswesens und der Kriegführung in der Ritterzeit von der Mitte des 11. Jahrhunderts bis zu den Hussitenkriegen,* vol. 3, Breslau 1887, pp. 181-182

[346] René Grousset, *Histoire de l'Asie*, vol. 3, Paris 1922, p. 127 (not seen, v. L. Bouvat in: Encyclopaedie des Islām, vol. 4, Leiden and Leipzig 1934, p. 1077).

[347] v. Edward S. Kennedy, *The heritage of Ulugh Beg,* in: Science in Islamic Civilisation, Istanbul 2000, pp. 97-109.

[348] Johannes Gravius, *Binæ tabulæ geographicæ, una Nassir Eddini Persæ, altera Ulug Beigi Tatari*, London 1652 (reprint in: Islamic Mathematics and Astronomy, vol. 50, pp. 1-79).

Amongst the noteworthy astronomical achievements of this century are also the extensive tables by Ġiyāṯaddīn al-Kāšī entitled *Zīǧ-i Ḫāqānī*, which the author compiled at Herat in 816/1413, even before the foundation of the Samarqand observatory. [65] Its geographical table shows a remarkable increase in the coordinates from Transoxania.

In the history of the development of astronomical instruments al-Kāšī occupies quite an important position as well. In his treatise on astronomical instruments he deals primarily with those of the observatory in Marāġa (infra II, 38 ff.); besides this, we should also mention a separate work entitled *Nuzhat al-ḥadā'iq*[349] in which he describes the two instruments which he calls *ṭabaq al-manāṭiq and lauḥ-i ittiṣālāt*. The former to our knowledge represents the ultimate stage in the development of an instrument called *zīǧ-i ṣafā'iḥ* invented in the first half of the 4th/10th century by Abū Ǧaʿfar al-Ḫāzin; this instrument was meant to determine mechanically the true position of a planet on the ecliptic at any given time, largely without the use of astronomical tables (supra p. 20). As mentioned above the original version of this instrument had found its way to Muslim Spain rather early on. The treatises written on it by Aṣbaġ b. Muḥammad Ibn as-Samḥ al-Ġarnāṭī (d. 426/1035) and Abu ṣ-Ṣalt Umaiya b. ʿAbdalʿazīz al-Andalusī (d. 528/1134), as well as the description of a substantially improved form of the instrument by Ibrāhīm b. Yaḥyā az-Zarqālī (2nd half 5th/11th c.), reached the non-Spanish Occident in the second half of the 13th century at the latest through their translation into Castilian in the *Libros del saber de astronomía.* The most advanced feature of al-Kāšī's instrument is his central alidade with a graduated parallel ruler with which the essential operations can be carried out by projection of simple markings, e.g. by placing it through the centre of a given deferent in order to find the true centre of the epicycle on the deferent at a given time.[350] From the fact that al-Kāšī's instrument shows a close similarity to the equatoria of G. Marchioni[351] (written in 1310) and to the one ascribed to Geoffrey Chaucer[352] (d. ca. 1400), I conclude that the latter two must have become acquainted with an older eastern specimen which was the model for al-Kāšī's instrument as well. As far as the second instrument, *lauḥ-i ittiṣālāt*, the "conjunction plate,"[353] is concerned, it was meant to serve for the mechanical computation of the expected days of conjunction of two planets on the basis of the differences, calculated beforehand, between the longitudes of each and the known differences between the distances traversed daily by the planets on their respective orbits. This type of computation device (made of wood or brass) is otherwise unknown.

In theoretical astronomy we shall also mention the interesting model for the planet Mercury developed by the above-mentioned ʿAlā'addīn ʿAlī al-Qūšǧī (d. 879/1474) which came to light just a few years ago.[354]

[66] In the field of mathematics, research has revealed many important achievements in the

[349] MS Princeton University, Garrett collection no. 75, edited with an English translation by Edward S. Kennedy, *The planetary equatorium of Jamshīd Ghiyāth al-Dīn al-Kāshī (d. 1429)*, Princeton NJ 1960.

[350] Derek J. Price, *The equatorie of the planetis,* Cambridge 1955, p. 131.

[351] v. Emmanuel Poulle, *Les instruments de la théorie des planètes selon Ptolémée: Equatoires et horlogerie planétaire du XIIIe au XVIe siècle*, vol. 1, Geneva and Paris 1980, pp. 192, 260 ff.

[352] Derek J. de Solla Price in: Isis (Baltimore, Ma) 54/1963/153 (review of E. S. Kennedy's edition of al-Kāšī's work); idem, Chaucer, in: *Dictionary of Scientific Biography*, vol. 3, pp. 217-218.

[353] v. E. S. Kennedy, *The planetary equatorium*, op. cit. pp. 78-161, 238-243.

[354] v. George Saliba, *Al-Qushji's reform of the Ptolemaic model for Mercury*, in: Arabic Sciences and Philosophy (New York) 3/1993/161-162; idem, *Arabic planetary theories after the eleventh century AD*, in: Encyclopedia of the History of Arabic Science, vol. 1, London and New York 1996, pp. 58-127, esp. pp. 123-125.

works of Ġiyāṯaddīn al-Kāšī analyzed so far; in many cases they represent the ultimate stage of development in the Arabic-Islamic culture and found their way to Europe several centuries later or had to be discovered again. Only a few examples shall be mentioned here.

In the history of algebra, al-Kāšī holds a special position through his in-depth study of equations of the fourth order. From a brief discussion of the subject in his "Key to Mathematics", *Miftāḥ al-ḥisāb,*[355] we learn that he knew 70 types (or 65)[356] of equations of the fourth degree and that he planned to treat them in a separate volume. It is presently unknown whether he actually found the time to do so or, if he did, whether the work is extant.

In this connection we may mention that in his *Miftāḥ al-ḥisāb* al-Kāšī gave some interesting examples of his treatment of the rules of summation of arithmetical and geometrical series of higher degrees. His summation of the series of the fourth degree reminds us of the achievement by his predecessor Ibn al-Haiṯam four hundred years earlier. However, al-Kāšī arrived at the result in his own masterly way.[357]

Historians of mathematics in the later part of the 19th century were surprised when Franz Woepcke[358] published the result of his research to the effect that Ġiyāṯaddīn al-Kāšī had used a very accurate method of approximation while calculating *sin* 1°, the like of which the Occident only came to know from François Viète (1540-1603).[359]

For the calculation of the daily movements of the planets al-Kāšī used a method of iteration. Although we already know the application of the iteration method from earlier scholars in connection with the computation of the lunar parallax, it occurs for the first time as a bona fide mathematical problem in al-Kāšī's work.[360]

Al-Kāšī's outstanding result in the mensuration of the circle has been known to the historiography of mathematics for fifty years. He criticises the results of his predecessors Archimedes, Abu l-Wafā' and al-Bīrūnī and their methods. He himself calculates the ratio circumference and diameter of a circle with the help of an inscribed and circumscribed polygon each with $3 \cdot 2^{28} = 805\,306\,368$ sides and thus arrives at $\pi \approx 3{,}14159265358979325$. Prior to Paul Luckey[361] making known this achievement, Johannes Tropfke[362] had stated that only with F. Viète and Adriaan van Roomen (1561-1615) had a "new, lustrous era" begun for the mensuration of the circle "in which through ever more precise calculations the approximation to the true value had been improved to an unexpected extent". With a method involving polygon calculation, Viète [67] established the value for π up to nine decimal points, von Roomen up to fifteen. Al-Kāšī in his days had already come up to seventeen decimal points.

In connection with the calculation of chords, al-Kāšī arrived at the trigonometric formula[363]

[355] Ed. Aḥmad Saʿīd ad-Damirdāš, Muḥammad Ḥamdī al-Ḥifnī, ʿAbdalḥamīd Luṭfī, Cairo, s.a., p. 199; ed. Nādir an-Nābulusī, Damascus 1977, pp. 413-414.

[356] v. A. P. Juschkewitsch, op. cit. p. 268; F. Sezgin, op. cit. vol. 5, p. 68.

[357] v. A. P. Juschkewitsch, B. A. Rosenfeld, *Die Mathematik der Länder des Ostens im Mittelalter*, op. cit. p. 90; F. Sezgin, op. cit. vol. 5, p. 68.

[358] *Passages relatifs à des sommations de séries de cubes extraits de deux manuscrits arabes inédits du British Museum de Londres*, in: Journal de mathématiques pures et appliquées (Paris) 2e série, 10/1865/83-116, esp. pp. 112-116 (reprint in: Islamic Mathematics and Astronomy, vol. 44, pp. 105-138, esp. pp. 134-138); F. Sezgin, op. cit. vol. 5, p. 63.

[359] v. F. Sezgin, op. cit. vol. 5, p. 65.

[360] v. E. S. Kennedy, *A medieval interpolation scheme using second order differences*, in: A Locust's Leg. Studies in honour of A. H. Taqizadeh, London 1962, pp. 117-120; F. Sezgin, op. cit. vol. 5, p. 65.

[361] *Der Lehrbrief über den Kreisumfang (ar-Risāla al-Muḥīṭīya) von Ǧamšīd b. Masʿūd al-Kāšī*, Berlin 1953 (reprint in: Islamic Mathematics and Astronomy, vol. 56, pp. 227-329).

[362] *Geschichte der Elementar-Mathematik*, op. cit. vol. 4, pp. 215-216; F. Sezgin, op. cit. vol. 5, p. 66.

[363] v. P. Luckey, *Der Lehrbrief über den Kreisumfang*,

which is known in the West under the name of Johann Heinrich Lambert (1728-1777):

$$\sin\left(45^\circ + \varphi/2\right) \neq \sqrt{\frac{1+\sin\varphi}{2}}.$$

Al-Kāšī also holds a distinguished position in the history of decimal fractions. Here the Arabic mathematician al-Uqlīdisī (4th/10th c.) was his eminent predecessor (supra p. 21). Yet al-Kāšī[364] was the first to treat the subject systematically. To our knowledge, decimal fractions only came to be commonly used in the Islamic world after al-Kāšī. In Europe, decimal fractions were introduced by the Jewish mathematician Immanuel Bonfils (mid 14th c.).[365] How he got into this position has yet to be explained. However, according to Juschkewitsch,[366] his brief sketch was "utterly insignificant compared with al-Kāšī's treatment of decimal fractions." There can hardly be any doubt that al-Kāšī's algorithm of decimal fractions must soon have reached Asia Minor and Constantinople through his disciples and successors or even through Byzantine travellers to Persia. In this connection we shall mention a surviving 15th century Byzantine arithmetic book[367] whose anonymous author knows how to reckon with decimal fractions and mentions that the Turks ruling the former Byzantine dominions commonly used such operations. The first systematic treatment of decimal fractions in Europe appeared in the small volume *De Thiende* ("The Tenth Part"), written in Flemish by the Dutch merchant, mathematician and engineer Simon Stevin (1548-1620).[368]

Regarding al-Kāšī's important achievements in the field of mathematics, we shall finally mention the chapter on regular and semi-regular bodies in his "Key to Mathematics". Of course, al-Kāšī had precursors in dealing with this matter; however, the complex calculations and constructions he presents with commanding skill, calculating the volumes of curvilinear circumscribed bodies, slanting cylinders and cones as well as other irregular hollow bodies, pointed arches, vaults, domes and stalactites, bear witness to the comprehensive expertise reached in Arabic-Islamic mathematics with al-Kāšī in the first half of the 9th/15th century.[369]

From the field of mathematics of this century we shall further mention that algebraic symbolism, developed in the western part [68] of the Islamic world from the 7th/13th century, reached a climax in the *Kašf al-maḥǧūb min ʿilm al-ġubār* by Abu l-Ḥasan ʿAlī b. Muḥammad al-Qalaṣādī (d. 891/1486).[370] "The first power, the square and the third power of an unknown are marked in the equations by the first letters of the words šaiʾ, māl and kaʿb and these characters too appear above the co-efficient."[371]

The progress made during the 9th/15th century in the field of cartography in the Arabic-

op. cit. p. 49 (reprint p. 283); F. Sezgin, op. cit. vol. 5, p. 66.

[364] v. P. Luckey, *Die Rechenkunst bei Ǧamšīd b. Masʿūd al-Kāšī mit Rückblicken auf die ältere Geschichte des Rechnens*, Wiesbaden 1951, pp. 102-114 (reprint in: Islamic Mathematics and Astronomy, vol. 56, pp. 75-225, esp. pp. 184-196).

[365] v. S. Gandz, *The invention of the decimal fractions and the application of the exponential calculus by Immanuel Bonfils of Tarascon (c. 1350)*, in: Isis (Bruges) 25/1936/16-45; P. Luckey, *Die Rechenkunst bei Ǧamšīd b. Masʿūd al-Kāšī*, op. cit. p. 120-125 (reprint op. cit. pp. 202-207); F. Sezgin, op. cit. vol. 5, pp. 67-68.

[366] A.P. Juschkewitsch, op. cit. p. 241.

[367] v. H. Hunger, K. Vogel, *Ein byzantinisches Rechenbuch des 15. Jahrhunderts. Text, Übersetzung und Kommentar*, Vienna 1963, p. 33; F. Sezgin, op. cit. vol. 10, p. 245.

[368] v. M. G. J. Minnaert, Stevin, in: *Dictionary of Scientific Biography*, vol. 13, New York 1976, pp. 47-51.

[369] A. P. Juschkewitsch, op. cit. p. 277; F. Sezgin, op. cit. vol. 5, p. 69; Yvonne Dold-Samplonius, *Practical Arabic mathematics: Measuring the muqarnas by al-Kāshī*, in: Centaurus (Copenhagen) 35/1992/193-242; idem, *The volumes of domes in Arabic mathematics*, in: Vestigia Mathematica. Studies in medieval and early modern mathematics in honour of H. L. L. Busard, ed. M. Folkerts and J. P. Hogendijk, Amsterdam and Atlanta 1993, pp. 93-106.

[370] F. Sezgin, op. cit. vol. 5, p. 62.

[371] A. P. Juschkewitsch, op. cit. p. 270.

Islamic area appears to have been very considerable. The most significant development with epochal consequences for the history of the world took place regarding the shape of the southern part of Africa, the depiction of which got very close to reality. In the Arabic-Islamic world the conviction that the African continent was circumnavigable in the south—contrary to the notion of the Indian Ocean as a land-locked sea held by Marinus and Ptolemy—can be traced back to the appearance of the world map by the Ma'mūn geographers in the first quarter of the 3rd/9th century. From a remarkable report by the historian and geographer Aḥmad b. Abī Yaʿqūb b. Ǧaʿfar al-Yaʿqūbī from the last third of the 3rd/9th century, we learn that merchant vessels built in Ubulla on the Tigris for the China trade, anchored in the Maghribi seaport Māssa (south of Agadir on the Atlantic coast) near the Bahlūl mosque.[372] The Ma'mūn geographers' depiction of Africa was based on the rough idea of a land mass, circumnavigable in the south and stretching eastwards to 160°. The mathematical survey of the large continent commenced some centuries later. The three oldest extant charts of Africa after the Ma'mūn map are the ones by al-Kindī and as-Saraḫsī (3rd/9th c.),[373] that by a 4th/10th or 5th/11th century anonymous,[374] and the one by al-Idrīsī (ca. 548/1154).[375] These maps are all either corrupt or crude reproductions of the map drawn for al-Ma'mūn. On the other hand, the depiction of Africa in the surviving sketchy world map by Naṣīraddīn aṭ-Ṭūsī (d. 672/1274, supra p. 47) turns out to be a considerable advance. This, in turn, is connected with the rendition of Africa on the type of Chinese world map which emerged in the early 14th century stimulated by the terrestrial globe sent to China from Marāġa in the year 1267, or other contemporary Arabic-Islamic maps. The crucial aspect in the depiction of Africa on these Chinese maps is the triangular shape of the southern part of the continent (supra p. 47), although the original dimensions of the map have suffered through the negligence of the copyists. In the depiction of the peninsular shape of Africa on European world maps[376] from Brunetto Latini (ca. 1265) to Fra Mauro (1459) there are still no traces of mathematical-astronomical methods. Of course that does not mean to say that no attempts had been made in the Islamic world at that time to determine the coordinates of places in Africa. In the tradition of the work begun in the early 3rd/9th century, extending in scope and gradually gathering momentum, measurements according to the rules of mathematical geography were taken from time to time. Yet it took time until the results would show themselves in maps. For a realistic depiction of the configuration [69] of an entire continent and beyond, continuous and organised efforts by generations would have been required.

Consequently it was considered quite a milestone in the history of geography and cartography when a perfect or near-perfect cartographic depiction of the configuration of Africa and South Asia including India was brought into circulation in Europe shortly after Vasco da Gama's return from his first expedition to India. Ignorance concerning the high level of mathematical geography, cartography and navigation based on scientific methods in the Arabic-Islamic world made it more difficult to identify the true originators of those maps. The accepted explanation was to the effect that those maps had been drawn up by Portuguese map-makers using data collected and provided by Vasco da Gama;[377] this explanation, on the one hand, betrays a complete lack of insight regarding the circumstances under which an accurate map of such a large part of the

[372] al-Yaʿqūbī, *Kitāb al-Buldān*, Leiden 1892 (reprint: Islamic Geography, vol. 40), p. 360; Christophe Picard, *L'océan Atlantique musulman. De la conquête arabe à l'époque almohade*, Paris 1997, pp. 31, 233-234, 248, 511; F. Sezgin, op. cit. vol. 11, pp. 383-384

[373] v. F. Sezgin, op. cit. vol. 10, pp. 136-137; vol. 12, p. 11.

[374] v. ibid, vol. 10, p. 134; vol. 12, p. 12.

[375] v. ibid, vol. 10, pp. 134-135; vol. 12, pp. 13, 18-19.

[376] v. ibid, vol. 10, pp. 549-550.

[377] v. ibid, vol. 11, pp. 354 ff.

Earth's surface alone could have been compiled, and, on the other hand, it shows that a wealth of historical evidence contradicting such an assumption was ignored. The disregard for cartographic reality may be exemplified by the case of the so called Cantino map, considered to be the first one drawn after Vasco da Gama's return from his first expedition, probably around 1502. A comparison of this world map with a modern one shows that the lines of the equator and of the two tropics are drawn accurately across Africa, the Arabian peninsula and India. The west-eastern extension of Africa at the equator and the distance between the equator and the Cape of Good Hope are almost the same on the Cantino map and the modern one (modern values are 33°30' and 34°30' respectively), while the distance between the east coast of Africa and the meridian of Cape Comorin (South India) at the equatorial line is about half a degree larger on the Cantino map than the modern value (35°).[378] Thus regarding the dimensions of the southern part of Africa and in the distance between the east coast of Africa and the southern-most point of the Indian peninsula, this world map displays an accuracy in longitude and latitude that was not matched by European maps of Europe and Asia prior to the 19th, in some respects even the 20th century. Hence, by the accuracy of the Cantino map, we may assume that this map offer clues leading to a model which was made locally and based on a sufficiently long-term survey in the area, collecting all the coordinates and distances required. It is hardly conceivable how Vasco da Gama, who had to reach south-west India on an established and fixed route and who had to return in the shortest possible time along that same route, could have procured the data required for the map, not to mention that this was neither his aim, nor his order. The voyages were of a mercantile and political nature. For the sake of justice it should be said that the Portuguese in those days did not claim to have created the prerequisites for making these maps themselves. Their task and achievement consisted in bringing as many maps drawn in foreign countries as possible to Portugal, where map-makers translated them into Portuguese, copied them and presented them according to their own understanding and taste. Most of the early Portuguese seafarers in the Indian Ocean make no secret of having seen maps with Arabic or other Muslim sailors quite often, or of having procured such maps. Amongst the reports known to us,[379] there is even a detailed report by [70] Vasco da Gama[380] himself about his first encounter with a Muslim navigator on the east coast of Africa. Da Gama relates how he saw maps with longitudes and latitudes in the hands of his Arabic colleague, which the latter used on his voyages. He was one of the navigators who piloted Vasco da Gama on the direct sea route to Calicut, on the west coast of India.

Other reports state that as early as in the first half of the 15th century maps of the Indian Ocean and of Africa, circumnavigable in the south, reached Portugal. Thus the sea route to India must have already been known to the Portuguese[381] before they, encouraged by such maps, endeavoured their expeditions, incorrectly referred to as "voyages of discovery".

With this brief exposition I intend to acquaint the reader with the conclusion I reached in the 11th volume of my *Geschichte des arabischen Schrifttums,*[382] viz. that the stage of cartographic depiction of Africa and the Indian Ocean reached just before the Portuguese expeditions was largely accurate and thus constitutes one of the most significant achievements of the Arabic-Islamic world in the 9th/15th century. The merit of the Portuguese consists in them having rec-

378 v. F. Sezgin, op. cit. vol. 11, p. 399

379 Ibid, vol. 11, pp. 323-336.

380 v. João de Barros, *Ásia. Dos feitos que os portugueses fizeram no descobrimento …*, Década I, Liv. IV, Cap. VI, ed. Lisbon 1945, pp. 151-152; F. Sezgin, op. cit. vol. 11, pp. 227-229.

381 v. F. Sezgin, op. cit. vol. 11, pp. 358-362

382 v. ibid, vol. 11, pp. 323-444.

ognised the importance of those maps, in collecting them and taking them to Portugal; thus they implemented their wide circulation in European languages and ultimately gave the impetus for an upsurge in cartographic activities in Europe. Otherwise, I could not see since when and through whose mediation those maps could have reached Europe, no longer just sporadically, but on a regular basis.

Concluding this topic, I would like to mention what I consider the greatest known cartographic achievement of the Arabic-Islamic world. We owe its discovery and preservation to the Portuguese. It is the "Javanese" atlas that fell into the hands of the Portuguese shortly after the conquest of Malacca in 1511 and was sent to King Emanuel I (d. 1521) by the conqueror Alfonso de Albuquerque.[383] In his accompanying letter to the king Alfonso writes: "I am sending you a part of the copy of a large map made by a Javanese pilot representing the Cape of Good Hope, Portugal, the country of Brazil, the Red Sea, the Persian Sea, the Spice Islands (the Moluccas), the sailing routes with the direct route to China and Formosa which the ships take along with the interior [of these countries] which adjoin one other. It seems to me that this is the most beautiful thing which I have ever seen. Your Majesty will be greatly pleased to see it. The place names are in Javanese characters, I had a Javanese who can read and write. I am sending Your Majesty that part, which Francisco Rodrigues copied from the original, in which Your Majesty will be able to see for yourself where the Chinese and the inhabitants of Formosa come from, what route your ships need to take to reach the islands of cloves, where the goldmines are, the islands of Java and Banda, the island of nutmegs and mace, the empire of Siam, the Cape of the Chinese, which they [71] sail round and where they turn round and do not go beyond. The original was lost with the Frol de la Mar (when it was shipwrecked). I have discussed the content of this map together with the pilot and Pero Dalpoem so that I might describe it to Your Majesty clearly. This map is very precise and well known because it is used in navigation. On the archipelago of the islands known as 'Selat' is missing (between Malacca and Java)".[384]

Modern cartography-history has failed to give a proper assessment of these maps and the question of their provenance, as it knows nothing about the mathematical navigation[385] which had provided crucial impulses for the cartography of the Indian Ocean in the course of the preceding development. With their longitudinal and latitudinal scales and near perfect configurations, the twenty-six extant parts of the atlas bear witness to a long tradition of cartography based on mathematical-astronomical principles. The atlas offers the earliest largely correct depictions known so far, of the Bay of Bengal, the Straights of Malacca and of the southern Chinese Ocean from Java across the Moluccas down to Canton. The island of Madagascar appears here for the first time on a map. Its delineation is so good that it was improved upon only by cartographers of the 19th and the first half of the 20th century. The fact that the atlas even includes the north-eastern coastline of South America[386]—mentioned also by Alfonso de Albuquerque, thus ruling out the option that it was a Portuguese addition—implies that the endeavour to advance the inherited cartographic world view according to the latest knowledge

[383] Santarem, *Atlas composé de mappemondes, de portulans et de cartes hydrographiques et historiques depuis le VIe jusqu'au XVIIe siècle*, Paris 1849 (reprint: Amsterdam 1985); A. Cortesão, *Cartografia e cartógrafos portugueses dos séculos XV e XVI*, vol. 2, Lisbon 1935, 126-130; idem, *The Suma Oriental of Tomé Pires and the Book of Francisco Rodrigues*, vol. 1, London 1944, preface pp.78-79; A. Cortesão and A. Teixeira da Mota, *Portugaliae monumenta cartographica*, vol. 1, Lisbon 1960, p. 80.

[384] v. F. Sezgin, op. cit. vol. 11, pp. 327-328

[385] On this, v. ibid, vol. 11, pp. 426-433.

[386] v. ibid, vol. 11, p. 441.

was still alive in the Arabic-Islamic area in the first decade of the 10th/16th century.

Such an advanced cartographic survey of the Indian Ocean and the African continent would have been impossible if cartography had not constantly benefited from the association with and the aid of scientific navigation. Today we are in the privileged position of knowing the specific nature of this navigation tolerably well. After a long evolution, it reached its climax in the Indian Ocean region during the second half of the 9th/15th century and in the first quarter of the 10th/16th century.

Navigation on the sea routes between Arabia and China dates back several millennia; the oldest preserved written documents dealing with this navigation date from the second half of the 9th/15th century. Even though is known that there was a body of writings concerning nautical rules and knowledge about routes, sea-ports and distances in the Indian Ocean at a much earlier time, unfortunately these writings were considered obsolete and got lost when the works of the two greatest exponents of navigation in the second half of the 9th/15th century and the first quarter of the 10th/16th century appeared, representing a higher development in the field.

The first of those two was Šihābaddīn Aḥmad Ibn Māǧid b. Muḥammad from Ǧulfār in the province of ʿUmān. A number of his works are extant and these also reflect a certain development in the knowledge and abilities of their author in the course of his life. According to Ibn Māǧid, navigation, which he calls *ʿilm al-baḥr*, is a "theoretical and empirical science, as opposed to a mere paper tradition" (*ʿilm ʿaqlī taǧrībī lā naqlī*).[387] He divides navigators into three groups. The first are the simple pilots whose voyages turns out sometimes well, [72] sometimes not, whose answers are sometimes right and sometimes wrong. These mariners do not deserve the title *muʿallim* ("master", sing.). The members of the second category, the average *maʿālima* ("masters", pl.) are known for the range of their knowledge. They are proficient, completely at home with the routes of the localities to which they sail, but once they die they are forgotten. The third class of navigators is the highest. Those who belong to it are widely known, command all the operations performed at sea and are scholars "writing treatises" from which one can benefit during their life time and also afterwards.[388]

Ibn Māǧid also mentions the regulations a captain has to observe during his voyage and the moral principles expected of him. He is conscious that an important position is assigned to his own person in the history of navigation and that his achievement shall not be without impact upon subsequent generations. ("There will come a time after us when it shall be possible to judge which position is due to each of us in our profession.")[389]

Ibn Māǧid[390] is convinced that he himself had advanced his field, notwithstanding his earlier works containing points that require correction. Interestingly he calls the material from his earlier writings he no longer wishes to uphold—in his present higher level of knowledge—"revoked" (*mansūḫ*) and that what replaces them "revoking" (*nāsiḫ*), thus using terms usually employed in connection with the revelation of the Qurʾān.

From Ibn Māǧid's extant works we learn unambiguously that he was indeed not merely a theorist, but had himself been a mariner for many years, sailing between Arabia, India and South East Asia. His books create the impression—perhaps not in quite as systematic a fashion as one might desire—that he represents a

[387] Ibn Māǧid, *Kitāb al-Fawāʾid fī uṣūl ʿilm al-baḥr wa-l-qawāʿid*, ed. I. *Ḫūrī*, Damascus 1970, p. 171; F. Sezgin, op. cit. vol. 11, p. 177.

[388] Ibn Māǧid, *Kitāb al-Fawāʾid*, op. cit. p. 171; F. Sezgin, op. cit. vol. 11, p. 177

[389] Ibn Māǧid, *Kitāb al-Fawāʾid*, op. cit. p. 18; F. Sezgin, op. cit. vol. 11, pp. 177-178.

[390] *Kitāb al-Fawāʾid*, op. cit. pp. 151-152; F. Sezgin, op. cit. vol. 11. pp. 178-179.

navigation based on the orientation to the North Star and to a number of other fixed stars (that rise and set on the horizon within a distance of approximately 11°15' from each other) and on the use of the compass. In his books he records the latitudes of hundreds of localities in the Indian Ocean area with compass bearings, but we find little information on how measurements of distances were taken. It seems, here and elsewhere, that Ibn Māǧid expects his reader to have a certain expertise. In one passage of his extensive work *al-Fawāʾid*[391] he discloses that some inventions in the field of nautical science are his own achievements, including an improvement of the compass where the magnetic needle itself is put on the compass, that is to say, it moves on top of the cardboard disc inscribed with the thirty-two bearing marks, rather than being fixed underneath.

In his surviving books Ibn Māǧid comes across as an accomplished, self-confident navigator with a thorough knowledge of astronomy and well versed in many other areas of knowledge of his times. His material reveals that we are here dealing with a mathematically surveyed Indian Ocean and with highly developed methods of navigation. Yet we learn how all this was accomplished and what the actual workings of this navigation were not so much from Ibn Māǧid as from his younger colleague, Sulaimān al-Mahrī. Adhering to the chronological principle which we follow here, Sulaimān al-Mahrī's more lucid [73] treatment of the subject shall be discussed in the context of selected topics of the 10th/16th century.

From the 9th/15th century we shall also mention two encyclopaedias which reflect the high standards of that time. One of them is the well known encyclopaedia of the art of writing and knowledge required for secretaries, written by the Egyptian secretary of state, Šihābaddīn Aḥmad b. ʿAlī al-Qalqašandī (b. 756/1355, d. 821/1418) entitled *Ṣubḥ al-aʿšā fī ṣināʿat al-inšāʾ*; it is divided into ten main sections comprising fourteen volumes.[392] Completed in 814/1412, this encyclopaedia, rich in content, systematically arranged, and with properly referenced sources can be regarded as one of the most impressive verfications of the cultural flowering across all areas of life in Arabic-Islamic society reached after a development of about eight hundred years.

The second important encyclopaedia from this century is a work which has so far remained largely unknown, the *Kašf al-bayān ʿan ṣifāt al-ḥayawān* by the versatile Alexandrian scholar Muḥammad b. Muḥammad b. ʿAlī al-ʿAufī[393] (b. 818/1415, d. 906/1501). This work, surviving in an autograph of sixty-two volumes,[394] is possibly the earliest encyclopaedic reference book to be arranged alphabetically, providing information on all fields of interest. Volume sixty-two breaks off with the letter *qāf* (i.e. only about two thirds were finished). The author cites the names of his sources, many of which are lost today. It is said they amount to three thousand titles.

[391] *Kitāb al-Fawāʾid*, op. cit. p. 192; F. Sezgin. op. cit. vol. 11, p. 261.

[392] v. Ferdinand Wüstenfeld, *Calcaschandi's Geographie und Verwaltung von Ägypten. Aus dem Arabischen*, in: Abhandlungen der Königlichen Gesellschaft der Wissenschaften zu Göttingen, historisch-philologische Classe, vol. 25, Göttingen 1879 (reprint in: Islamic Geography, vol. 52, pp. 1-223); Bernard Michel, *L'organisation financière de l'Égypte sous les sultans mamelouks d'après Qalqachandi*, in: Bulletin de l'Institut d'Égypte (Cairo) 7/1924-25/127-147 (reprint in: Islamic Geography, vol. 52, pp. 225-245); Walther Björkman, *Beiträge zur Geschichte der Staatskanzlei im islamischen Ägypten*, Hamburg 1928 (reprint: Islamic Geography, vol. 53); C. Brockelmann, op. cit. vol. 2, p. 134, suppl.-vol. 2, pp. 164-165.

[393] Naǧmaddīn Muḥammad b. Muḥammad al-Ġazzī, *al-Kawākib as-sāʾira bi-aʿyān al-miʾa al-ʿāšira*, vol. 1, Beirut 1945, pp. 14-17; C. Brockelmann, op. cit. vol. 2, p. 57, suppl. vol. 2, p. 58.

[394] Vols. 2-62 are preserved in the collection Feyzullah (No. 1687-1745, İl Halk Kütüphanesi) in Istanbul, vol. 1 in the collection Süleymaniye (No. 873, Süleymaniye Kütüphanesi), a late copy of this is in Paris, Bibliothèque nationale, ar. 4825.

Following this colossal encyclopaedia we should mention another work which reflects the pronounced interest of that time in cultural history and the vision of its author with regard to history. A little known scholar from Damascus, ʿAbdalqādir b. Muḥammad an-Nuʿaimī[395] (d. 927/1521), took it upon him to write the history of the schools and universities of his hometown from around the 5th/11th to the 10th/16th centuries. Surviving in two volumes under the title *ad-Dāris fī taʾrīḫ al-madāris,*[396] the work deals with the mosques, monasteries and tombs attached to the schools and is apparently an extract from the author's *Tanbīh aṭ-ṭālib wa-iršād ad-dāris fīmā fī Dimašq min al-ǧawāmiʿ wa-l-madāris*. It informs, inter alia, "about the career and works of scholars, about their peculiarities and attire, about quarrels ended by intervention of the Sultan, about edicts (*tawāqīʿ*) from Egypt through which teachers were transferred and textbooks replaced. Some teachers had only a part-time position (*niṣf tadrīs*)."[397] The importance of this book becomes evident when one tries to find its like in the Europe of that time.

[74] The 10th/16th Century

The great observatory founded in Istanbul between 1575 and 1580 under the Ottoman sovereign Murād III is one of the achievements of the 10th/16th century to be mentioned in this overview. The idea was suggested to the Sultan by the versatile scholar Taqīyaddīn Muḥammad b. Maʿrūf ar-Raṣṣād. With a "new kind of observation" (*raṣad ǧadīd*) using newly built instruments of large dimensions, the latter intended to collect substantially improved results. The surviving Turkish book on the observatory and its instruments contains the description and illustrations of eight observational devices of hitherto unknown proportions. It was probably first dictated in Arabic by Taqīyaddīn (who had only settled in Istanbul in the 1550s after sojourns in Damascus and Cairo). Two of the instruments seem to have been devised by Taqīyaddīn himself, the other six already figure in the instruments book of the observatory at Marāġa built three hundred years earlier (supra p. 41 f.). One may assume that news about the Istanbul observatory soon reached Europe and that the great astronomer Tycho Brahe (1546-1601) also heard about it. At any rate, the similarity between two of the instruments in Taqīyaddīn and Tycho Brahe (viz. the instrument for measuring the distances between celestial bodies and the wooden quadrant, infra II, 64, 68) create this impression. Moreover, Stefan Gerlach, pastor of the German emperor's ambassador in Istanbul, reports at length on the foundation of the observatory in his 'Turkish Diary' (*Türckisches Tagebuch)* entry 13th November 1577.[398] Salomon Schweigger, another clergyman in the entourage of a western ambassador, stayed in Istanbul from 1st January 1578 to 3rd March 1581 and wrote about the event with a strong bias, which itself is quite interesting for the history of culture and science. In his travelogue he calls Taqīyaddīn "a wretched blockhead" who "some years ago had been held prisoner in Rome, where he learned much about the arts of a mathematician whose servant he was and thus became such a celestial artist and planetary jester." Allegedly, he even had Arabic translations of works by Ptolemy, Euclid, Proclus and "other writings by famous astronomers" secretly explained to him by a Jew.[399] It goes without saying that these assertions are not correct and that

[395] v. C. Brockelmann, op. cit. vol. 2, p. 133, suppl. vol. 2, p. 164.

[396] Ed. by Ǧaʿfar al-Ḥasanī, 2 vols., Damascus 1948, 1951.

[397] W. Björkman, review of the edition in: Oriens 5/1952/178.

[398] v. J. H. Mordtmann, *Das Observatorium des Taqī eddīn zu Pera*, in: Der Islam (Berlin and Leipzig) 13/1923/82-96, esp. pp. 85-86 (reprint in: Islamic Mathematics and Astronomy, vol. 88, pp. 281-295, esp. pp. 284-285).

[399] *Ein newe Reyssbeschreibung auß Teutschland Nach Constantinopel und Jerusalem*, Nuremberg 1608 (reprint in: The Islamic World in Foreign Travel Accounts, vol. 28, Frankfurt 1995), pp. 90-91.

Taqīyaddīn's stay in Rome is pure fiction. Yet the acerbity with which the spirit of antagonism towards the Arab-Islamic area makes its appearance here, draws our attention; a tendency that had already begun in the 13th century but now, from the second part of the 16th century, was combined with a feeling of superiority in the sciences, which, even though perhaps not quite justified yet, shortly afterwards was to become real.

The observatory in Istanbul was established in succession to the two precursors in Marāġa and Samarqand, whose fame had spread beyond the Islamic world. After many years of work as an astronomer and physicist, its founder, Taqīyaddīn, moved to Istanbul in the 1550s to place his knowledge and abilities in the service of Murād III. The latter was intelligent enough to grant the request and have the costly observatory built, [75] but he was not intelligent enough to appreciate its true merits. Thus he could be persuaded by fanatical advisers and the adversaries of Taqīyaddīn to demolish the observatory as an alleged instrument of astrology with a corrupting influence on the state only a few years after its foundation.

Taqīyaddīn was possibly the first astronomer to introduce time as a distinct parameter in his observations. For this purpose he built a large astronomical clock (*bingām raṣadī*) as an addition to the instruments of the observatory (infra III, 117). Taqīyaddīn enjoyed considerable fame in the Ottoman Empire not only as a *rāṣid* (observing astronomer) but also as a *muhandis* (engineer). From his two extant treatises on pneumatic constructions and clocks he indeed emerges as an eminent physicist and technician. In his book on pneumatics, *aṭ-Ṭuruq as-sanīya fī l-ālāt ar-rūḥānīya*[400] written in 953/1546, Taqīyaddīn describes a number of machines and devices that reveal an already well-developed level of technology. The precise descriptions enabled us to reconstruct several devices without great difficulty; of these, we may first of all mention an automatic pump with six piston-like plungers powered by the current of a river, transferred through a waterwheel onto a camshaft. The cams in turn move six levers which drive the plungers. This type of waterwork with six plungers appears for the first time in Taqīyaddīn's book. About 350 years earlier ar-Razzāz al-Ǧazarī (supra p. 37) had already known waterworks with two plungers. Thus it is possible that there was an intermediate stage of development in the period between the two authors. In this respect it is interesting that Taqīyaddīn praises a work by ʿAlī al-Qūšǧī (d. 879/1474) on pneumatics and mentioned as one of his sources.[401] At the present time it is not known whether the concept of waterworks with multiple pistons as described shortly afterwards in Europe by Georgius Agricola[402] (1494-1555) and Agostino Ramelli[403] (1531-1600?) was connected with the Arab-Islamic world or whether it developed independently.

Taqīyaddīn also describes the two types of mechanised turnspits for roasting meat most common in his time, one of which is turned by steam and the other by hot air.

The description of the second device resembles a turnspit-construction sketched by Leonardo da Vinci which was also intended to be powered by hot air (infra V, 39). Moreover, Taqīyaddīn describes numerous devices func-

[400] Ed. by Aḥmad Y. al-Ḥasan in his *Taqīyaddīn wa-l-handasa al-mīkānīkīya al-ʿarabīya*, Aleppo 1987.

[401] In his *al-Kawākib ad-durrīya fī waḍʿ al-bingāmāt ad-daurīya*, ed. Sevim Tekeli in *16'ıncı asırda Osmanlılarda saat ve Takiyüddin'in "Mekanik saat konstrüksüyona dair en parlak yıldızlar" adlı eseri,* Ankara 1966, pp. 46, 144, 221.

[402] *De re metallica. Translated from the first Latin edition of* 1556… by Herbert C. Hoover and Lou H. Hoover, London 1912 (reprint New York 1950), pp. 185-189.

[403] *The various and ingenious machines of Agostino Ramelli. A classic sixteenth-century illustrated treatise on technology.* Translation and biographical study by Martha Teach Gnudi, annotations … by Eugene S. Ferguson, Toronto 1976 (reprint New York 1994), pp. 258-259, plate 97.

tioning by transmission of force with cogwheels. They must have been very common in his days. He refers to one of them as his own invention.

In the field of mathematical geography, in the 10th/16th century we encounter tables of coordinates and maps that display an increase in the mathematically surveyed parts of the oikoumene and an enhanced cartographic depiction. It is of course impossible to say in each case whether the progress had really only been achieved by the 16th century or whether it dates back to the preceding one. One of the most significant extant documents of the high standard reached in the cartography [76] and navigation of the Mediterranean is the *Kitāb-i Baḥrīye* of the Ottoman seafarer Pīrī Reʾīs (ca. 1465-1554), who defines the term *baḥrīye* as the "science of the oceans and the technology employed by mariners". This monumental work testifies to the author's great literary maturity. It is his consistently pursued aim to enable an optimized voyage in the Mediterranean on the basis of detailed physico-geological, archeological and meteorological data. Besides the enormous amount of data collected for that purpose, Pīrī Reʾīs furnished his book with more than 200 charts of islands, harbours and some coastal regions of the Mediterranean of astounding quality which, undoubtedly, can only be understood as the result of a long-term development. Unfortunately, recent researchers have so far paid less attention to the contents and the detailed maps of the book than to the fragments of his world map. This he himself calls the most comprehensive world map in circulation at the time. To our knowledge it is the last attempt made in the Arab-Islamic culture area to create an up-to-date world map on the basis of all accessible sources.[404]

Another Ottoman document from the time of the second edition of Pīrī Reʾīs's work testifies indirectly to a rather highly developed and once again extended world map. The "time keeper" (*muwaqqit*)[405] of the Selīmīye mosque in Istanbul, Muṣṭafā b. ʿAlī al-Qusṭanṭīnī al-Muwaqqit (d. 979/1572), when still a young man, dedicated his booklet *Iʿlām al-ʿibād fī aʿlām al-bilād*[406] to Sultan Süleymān (r. 926/1520-974/1566) in the year 931/1525; in it he gives the longitudes and latitudes of 100 localities and their rectilinear distances from Istanbul in miles. Those places are more or less well known cities in the northern hemisphere, located between the west coast of Africa and the east coast of China. What makes this heterogeneous compilation important is, firstly, that longitudes in it are given consistently according to the prime meridian (shifted by 17°30' to the west of the Canary Islands in the Atlantic Ocean), hence the significantly revised longitudes of the world map must have been commonly known in the early Ottoman empire; secondly, that it documents how the part of the world mathematically surveyed in the Arab-Islamic region was further extended at that time. The coordinates recorded in this book show that the main points of the configuration of the Mediterranean, the Black Sea and Anatolia almost match the modern values. Moreover, they corroborate contemporary values known to us from other sources.[407] Yet the greatest importance of this book regarding the history of cartography lies, in my opinion, in the fact that it includes the earliest known coordinates of the northern Siberian fortress Armayat ar-Rūs, later to be known as Tobolsk. The longitude given is quite close to the actual value, while the latitude deviates from the modern value by only 15'.[408] This, of course, is not only a confirmation of our assumption that the mathematical survey of northern Asia had be-

[404] v. F. Sezgin, op. cit. vol. 11, pp. 42-48.

[405] Later the head-astronomer (*müneğğim-baši*) and predecessor of Taqīyaddīn, v. E. İhsanoğlu, R. Şeşen, C. İzgi, C. Akpınar, İ. Fazlıoğlu, *Osmanlı astronomi literatürü tarihi*, vol. 1, Istanbul 1997, pp. 161-179.

[406] Regarding the manuscripts, v. ibid, vol. 1, pp. 162-163.

[407] v. F. Sezgin, op. cit. vol. 10, pp. 181-191, 452-454.

[408] v. ibid, vol. 10, pp. 188, 191.

gun in the Arab-Islamic world relatively early on, namely around the 7th/13th century,[409] but it is also the earliest evidence so far that Ottoman geographers and cartographers [77] must have possessed a fairly accurate cartographic depiction of these areas, certainly by the first quarter of the 10th/16th century. What's more, this document offers us the first clue as to from where exactly a 16th century European cartographer like Gerard Mercator could have acquired his latitude for the city of Tobolsk (58°), a question which has so far apparently never been posed in the history of cartography.[410]

From the descriptive branch of geography we can also cite an interesting example demonstrating that science in the Islamic world was still at a comparatively high level in the 10th/16th century. The example is provided by the scholar al-Ḥasan b. Muḥammad al-Wazzān (b. around 888/1483), known in Europe as Leo Africanus. Born in Granada, he grew up and received his education in Fās (Fez, now Morocco); in diplomatic service he travelled to various Islamic countries, particularly of northern Africa, and, as a writer, developed an interest in geography and local cultures. On the way back from Istanbul he fell into the hands of Sicilian corsairs and was sold first to Naples and then to Rome where he was baptised by Pope Leo X, after the latter's own name, Giovanni Leo on January 6, 1520. During his stay in Italy he learned Italian and taught Arabic. In 935/1529 he returned to Tunis where he died as a Muslim. In Rome and Bologna he had continued his literary work. Besides a description of Africa, he compiled a work comprising thirty biographies of north-African scholars. His description of Africa in Italian was completed in 1526, the sixth year of his captivity. The book consists of nine chapters. The first deals with the general physical and climatic characteristics of Africa and with its inhabitants. The second deals with the region of Marrākuš (Marrakesh) with its cities and mountains, the third with Fās, the fourth with Tilimsān (Tlemcen), the fifth with Tunesia, the sixth with Libya, the seventh with the Sudan, the eighth with Egypt and the ninth with the rivers, natural resources, the flora and fauna of Africa. All in all some 400 localities are introduced. The author remarks that he had relied primarily on his own observations but, where he could not provide any information himself, had taken pains to obtain detailed reports from reliable and knowledgeable people.

Next to al-Idrīsī's *Nuzhat al-muštāq*, Leo Africanus's description of Africa was one of the most important sources available in Europe from the second half of the 16th century as a basis for the development and expansion of the descriptive geography of Africa. Shortly after the book was printed by G. B. Ramusio in the year 1550,[411] it was translated and adapted into several languages.[412] In the preface to his French translation, Ch. Schefer made an excellent study on the way in which European authors, from the 16th to the 18th century, depended on Leo Africanus's book.[413]

The maps of Africa and South Asia which were probably introduced to Italy by Leo Africanus had a substantial influence upon the further development of cartography in Europe. Copied by Ramusio and circulating under both their names, those maps are southern-oriented according to Arab custom and, with their scales of longitude and latitude, clearly betray an Arab origin.[414] They led to a break with the [78] cartographic depiction of the oikoumene that had

[409] v. ibid, vol. 10, pp. 383-396

[410] v. F. Sezgin, op. cit. vol. 10, p. 388

[411] Gian Battista Ramusio, *Navigationi et viaggi,* vol. 1, 3rd ed. Venice 1563 (reprint: Amsterdam 1970), folios 1-95.

[412] v. F. Sezgin, op. cit. vol. 11, p. 103, note 1.

[413] *Description de l'Afrique tierce partie du monde, écrite par Jean Léon African, ... mise en François*. Nouvelle édition annotée par Charles Schefer, 3 vols., Paris 1896-1898 (reprint: Islamic Geography, vols. 136-138, Frankfurt 1993), preface vol. 1, pp. 30-36.

[414] v. F. Sezgin, op. cit. vol. 11, pp. 102-103, vol. 12, pp. 306-310.

emerged after the publication of Ptolemy's Geography in the early 16th century. The turning-point is marked by the Asia map by the Italian cartographer Giacomo Gastaldi (d. 1567), which appeared around 1560. Before that, from 1539, Gastaldi had been devoted to the publication of Ptolemaic maps.[415]

The development of mathematical geography and cartography on the Indian subcontinent, which is still hardly understood in detail, ought to be considered here as well. As mentioned above, in the first half of the 5th/11th century, al-Bīrūnī himself had already determined the coordinates of some important points on the Indian subcontinent in the course of an extended project. This was the most that an exceptionally assiduous scholar could possibly achieve in several years of hard work. The remaining work took the subsequent generations several centuries to finish. According to our current knowledge, the latitudes of key points on the coast and bearings between these seem to have been determined in the 7th/13th and the 8th/14th centuries to such an extent that a delineation of the peninsula's configuration became feasible.[416] It was decisive for the beginning of the mathematical survey of the inland areas of the country that the scientific activities of the Samarqand school of the Tīmūrid period were relocated to India, together with political power, after the foundation of the Mogul empire by Bābur in 932/1526. In the following period, lasting about two centuries, emphasis seems to have been placed on collecting data for the mapping of the inland areas. The oldest known document of this type goes back to the second half of the first century of the Mogul Empire. It is a large volume of tables produced in India itself. Its author, Abu l-Faḍl ʿAllāmī (b. 958/1551, d. 1001/1593), was a statesman from the realm of the Mogul emperors. In the third part of his *Akbarnāma*, a history of the Mogul Empire, which under the independent title *Āʾīn-nāma* combines anthropogeography with an excellent descriptions of social, administrative and fiscal institutions, he provides a large table of coordinates with 656 places including 45 cities in India, and registers 3050 smaller towns, partly specifying distances. The quality of the coordinates of the Indian places is consistently high. The latitudes are almost identical with present-day values and the longitudes differ just slightly.[417] The data compiled in the *Āʾīn-nāma* which were probably selected from special contemporary sources and the abundant material from the first half of the 11th/17th century[418] convince us that the mathematical survey of the Indian subcontinent had reached a high standard under Islamic rule. Credit for the oldest known document showing the remarkable standard in the depiction of India in the 10th/16th century must go to the Dutchman Jan Huygen van Linschoten. In 1596 he published a map in Amsterdam that he had brought back from India.[419]

Here we leave the cartography of the Indian subcontinent and proceed to the science of navigation in the Indian Ocean. Even though it apparently had reached its climax as early as in the 9th/15th century, the specifics of this navigation based on trigonometric-astronomical methods [79] were expounded only in the first quarter of the 10th/16th century in the works of Sulaimān al-Mahrī. This latest master navigator known to us also regarded navigation as a science consisting of theory and experience, and, particularly as regards details, subject to the law of evolution. From this discipline, which over the centuries developed into an independent branch of science, we shall mention the three pillars on which it rests:

1. Determining the latitude at sea using the pole star and the circumpolar stars whose upper and lower culminations serve for determining

[415] v. F. Sezgin, op. cit. vol. 11, pp. 92-93, 97, 99 ff., vol. 12, pp. 177-181, 252, 311.

[416] v. ibid, vol. 11, pp. 565-567.

[417] v. ibid, vol. 10, pp. 193-194.

[418] v. ibid, vol. 10, pp. 194-202.

[419] v. ibid, vol. 12, p. 252; B. J. Slot, *The origins of Kuwait*, Leiden etc. 1991, pp. 13-15.

the altitude of the pole which in turn yields the geographical latitude of a place.

2. Mathematical-astronomical measurements of distances on the open sea, distinguished by Sulaimān al-Mahrī with the term *ḥisābī* ("mathematical") from those that are achieved empirically, "according to experience" (*taǧrībī*).[420]

3. Determining of the position on the open sea. Here the distances to be measured and the methods of measurement are of three kinds:

a) The first and most simple case is the latitudinal distance, running parallel to the meridian. For its determination it is sufficient to measure the altitude of the pole while setting out and once again after sailing for some time; the measurements are taken either in degrees or the thumb-width unit *iṣbaʿ* (1 *iṣbaʿ* = 1°36'26" or 1°42'51"), the difference can be converted into distances.

b) In the second case the distance may run at any angle oblique to the meridian. It is found by taking, in degrees, the altitude of the pole and measuring the angle of the course to the meridian at the time of putting to sea. After sailing for some time on that course, the altitude of the pole is again taken. With this data, a right-angled triangle is constructed. The hypotenuse, i.e. the side opposite to the right angle, is the sought distance.

c) In the third case the distance is longitudinal. This was used for measuring distances between places of the same latitude situated on opposite seacoasts, i.e. determining distances parallel to the equator. The method is equivalent to the determination of longitudinal differences between two points on the coast or at sea. The navigator first proceeds as described under b), that is to say, he sails a certain distance at a known angle oblique to the meridian. After determining this first distance he takes a course opposite to the one sailed before and maintains this course until he reaches the same altitude of the pole that was registered at the outset. With the known angles of the courses and the difference in the measured altitude of the pole, the navigator constructs two right-angled triangles with one common side, consisting of the measured difference in the altitudes of the pole. In order to arrive at the sought longitudinal difference between the two opposite coastal points, the navigator must continue cruising between the two established altitudes of the pole until he has reached the desired coastal point. By adding up the base lengths of all triangles he finally gets the total distance in *zām* to be converted in degrees of longitudes or miles.

Procedure c) was in the true sense of the word triangulation on the high seas, roughly five hundred years after Abu r-Raiḥān al-Bīrūnī used the triangulation method on land for establishing longitudinal differences of localities between Baghdad and Ghazna. In order to handle this method, the application of trigonometric rules was required, besides a certain knowledge of astronomy. This mathematical method was well developed and widespread in the Arabic-Islamic world, but of course it was not suitable for every mariner to use. Those lacking the required skills could resort to available tables while measuring distances oblique to the meridian.

[80] Prior to the introduction of the compass, orientation on the open sea and maintaining a set course at night was guided in the Indian Ocean by the North and South Star and by fifteen fixed stars which in their points of rising and setting are approximately 11°15' apart; this led to a division of the horizon in thirty-two parts. The time when the knowledge of the compass reached the Arabic-Islamic area cannot be precisely determined, but it was presumably in the 3rd/9th or 4th/10th century. It seems that the magnetic needle in its primitive form originated in China, but was first systematically used for navigation by the navigators of the Indian Ocean.[421] Besides the numerous references in Arabic sources, the Portuguese also frequently provide perspicuous information on the various types of compasses

[420] v. F. Sezgin, op. cit. vol. 11, p. 199.

[421] v. F. Sezgin, op. cit. vol. 11, pp. 232-265.

used in the Indian Ocean. The Portuguese historian Hieronimus Osorius (1506-1580) gave a particularly impressive account of the three stages in the development of the compass with Arab navigators.[422] In the third type, the bowl carrying the disc with the magnetic needle was suspended in a cylindrical arrangement which later came to be known as "cardan" suspension. This type apparently already reached the Italian seafarers in the Mediterranean in the 15th century, and also Christopher Columbus took such a compass with him.[423] It was the type of mariner's compass commonly used in Europe until the 20th century, when the magnetic needle was separated from the cardboard disc and placed on a pin above the disc. If we understand Ibn Māǧid's statement correctly (supra p. 72 and III, 67), he was the originator of this innovation which at first obviously did not enjoy much circulation.

The distances between ports, islands, capes and bays of the Indian Ocean recorded by the two great navigators, Ibn Māǧid and Sulaimān al-Mahrī, are remarkably close to modern values. Of the greatest significance are particularly the seven trans-oceanic distances given by al-Mahrī, between the east coast of Africa and Sumatra or Java; of these the route passing approximately 1° north of the equator deviates by only half a degree from the present-day value.[424] Quite remarkably the same precise length of the equator appears around 1519 in a map drawn in Portugal by Jorge Reinel—which can only mean that a copy from an Arabic original served as a model here. Such accuracy was not found again until the second half of the 19th or even to the first half of the 20th century.[425]

We can take for granted the fact that such data, collected for centuries in the context of a navigation based on mathematics and astronomy, would lead, in the hands of cartographers, to maps of high quality. While Portuguese seafarers and other European travellers repeatedly mention nautical charts by local navigators on the Indian Ocean and in particular point out that longitudes and latitudes were indicated on these maps;[426] some of those charts survive in Portuguese copies. The fact that the two great representatives of navigation in the Indian Ocean hardly ever mention any maps was used by some historians of cartography to argue that this nautical aid was unknown or unavailable to them. The lacuna is now filled by the [81] *Kitāb al-Muḥīṭ* ("Book of the Ocean") by the Ottoman admiral Sīdī ʿAlī (d. 970/1562), which only was made fully accessible to research in a facsimile edition a couple of years ago.[427] This naval officer, who was usually operating in the Mediterranean, had suffered great losses through Portuguese attacks while fulfilling a mission in 960/1553 to take fifteen ships of the Ottoman fleet from al-Baṣra to as-Suwais (Suez). The remainder of his fleet landed near Sūrat on the west coast of India. During a subsequent stay in Aḥmadābād (961/1554) he wrote his book, basically summarising the contents of several works by Ibn Māǧid and Sulaimān al-Mahrī.[428] In the four sections of the seventh chapter devoted specifically to maps, his presentation leaves no doubt that a navigation based on the calculation of distances and determination of bearings could not do without appropriate charts, neither in the Mediterranean nor in the Indian Ocean. He mentions three types of maps: charts of the

[422] Jerónimo Osório, *De rebus Emmanuelis libri XII*, Cologne 1574, Liber I, folio 27a ff.; F. Sezgin, op. cit. vol. 11, pp 253-256.

[423] v. F. Sezgin, op. cit. vol. 11, p. 253.

[424] v. ibid, vol. 11, pp. 214-219.

[425] cf. ibid, vol. 11, pp. 93-99.

[426] v. ibid, vol. 11, pp. 323-336.

[427] ed. by the Institut für Geschichte der Arabisch-Islamischen Wissenschaften, Frankfurt 1997.

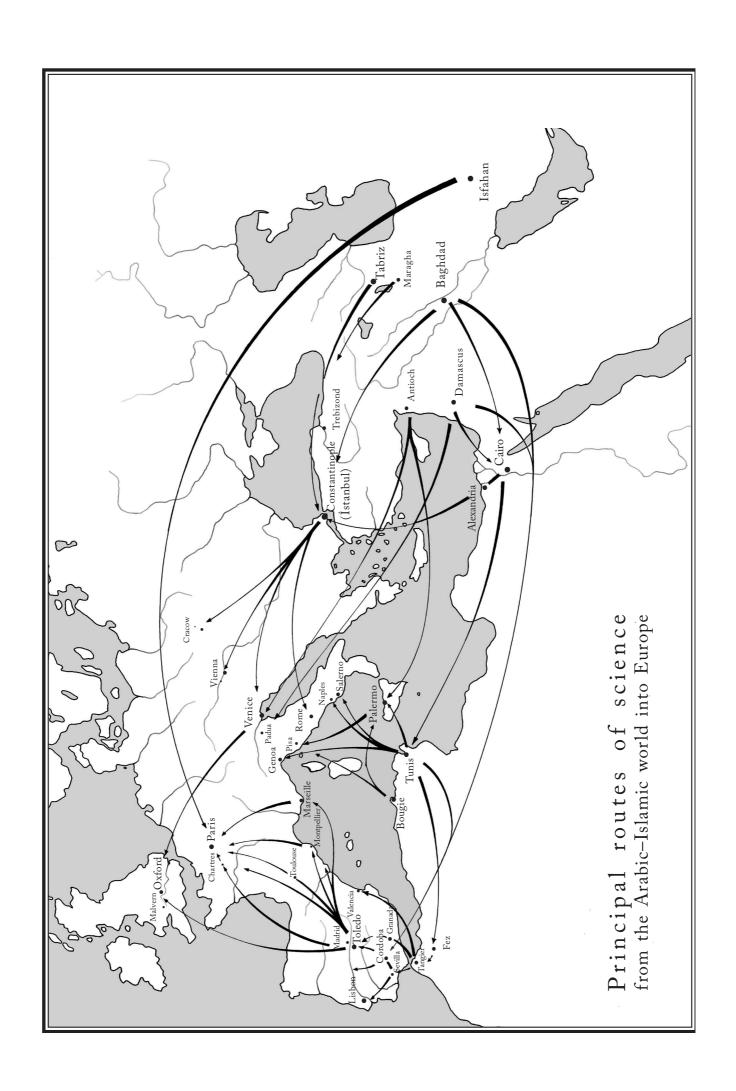
[428] v. *Die topographischen Capitel des indischen Seespiegels Moḥîṭ*, übersetzt von Maximilian Bittner, … mit einer Einleitung … von Wilhelm Tomaschek…, Vienna 1897, pp. 2-3 (reprint in: Islamic Geography, vol. 16, pp. 129-254, esp. pp. 136-137).

Indian Ocean, of the Mediterranean, and world maps. On the whole, it becomes clear that he understands maps as the representation of the mathematically surveyed surface of the Earth and that for him navigation can be practised only with the help of charts, magnetic compasses, dividers, and instruments such as the astrolabe or the quadrant.[429]

Besides the charts of the Indian Ocean supported by the measurements taken by navigators and besides the two main nautical instruments—the compass and the surveying instrument known in Europe as Jacob's staff[430] or *balhestilha* (Arabic *ḫašabāt* or *ḫaṭabāt*)—the method of measuring distance oblique to the meridian was also introduced into Europe. It was called *toleta de marteloio* and reached Italy in the 15th century.[431] Regarding the advanced navigation which originated in the Indian Ocean, the Portuguese deserve the credit for having helped its wide dissemination in Europe, within the bounds of their understanding. However, it has been established beyond doubt that the measuring of distances between two points of the same latitude on opposite coasts, i.e. the determination of trans-oceanic longitudinal differences—perhaps the most significant achievement of this nautical tradition—remained a closed book to them. That is, they appear to have known the problem as such,[432] but it seems they lacked the necessary trigonometric expertise to understand the procedure.[433]

With this overview of the field of navigation I would have concluded my survey of the most important achievements of the Arabic-Islamic world known to me, and would have moved on to the discussion of their influence on the western world, yet I feel that by completely excluding the 11th/17th century I would do injustice to an eminent philosopher of this period. I am referring to Ṣadraddīn Muḥammad b. Ibrāhīm Šīrāzī, known as Mullā Ṣadrā (b. ca. 980/1572, d. 1050/1640) whose important position in the history of philosophy was brought to light only in 1912 thanks to Max Horten. The latter called Mullā Ṣadrā "one of the great unknown figures in the history of humanities. In the narrow and meagre confines of the teaching profession he found time and energy to expound his own view of the world" [82].[434] Based on Šihābaddīn as-Suhrawardī's (d. 587/1191) light-theory, he formulated his theory of "evolutionary stages of being" in which "the concept of light was replaced by being." Through this shift Šīrāzī came to "a point of view from which he remodels the entire philosophy of his days."[435] With great self-assurance, so Horten, he confronts the current philosophy. In his system he combines the entire heritage of Greek philosophical learning with mysticism. He considers Aristotle and Ibn Sīnā as the greatest philosophers ever. They are followed by Plato and as-Suhrawardī; Faḫraddīn ar-Rāzī (d. 606/1209) is esteemed as the great critic of Aristotelian philosophy. However, according to Horten, Mullā Ṣadrā's philosophy was not merely borrowed from the teachings of those masters, but was a deliberate attempt at a continuation of Ibn Sīnā.[436]

With this brief reference to the importance of Mullā Ṣadrā in the field of philosophy, I conclude the examples for the contribution made by the Arabic-Islamic world area to the history of science. This closing however is not meant to imply that subsequently there were no occasional further achievements of significance. Yet with the end of the 10th/16th century we find ourselves on the threshold of the period in which, in the field of sciences, the West begins to take the

[429] v. F. Sezgin, op. cit. vol. 11, pp. 265-268.
[430] v. ibid, vol. 11, pp. 302-306
[431] v. ibid, vol. 11, pp. 289-294.
[432] v. ibid, vol. 11, p. 287.
[433] v. ibid, vol. 11, p. 319.

[434] Max Horten, *al-Šīrāzī*, in: Enzyklopädie des Islām, vol. 4, Leiden and Leipzig 1934, p. 407.
[435] *Das philosophische System von Schirázi (gest. 1640)* Translated and explained by M. Horten, Strasbourg 1913 (reprint in: Islamic Philosophy, vol. 92), preface p. V.
[436] Ibid, preface, pp. VIII-IX.

lead in the field of sciences and in which it will relieve the Islamic world of this role. Keeping this in mind, the present overview would fail its aim if the enormous complex of the reception and assimilation of Arabic-Islamic science in the Occident remained outside our purview. However, within the confines of this introduction, such an attempt can only consist in hints towards the most basic issues, particularly as a comprehensive presentation of the matter, apt to historical reality, cannot also be expected for a long time to come.

Principal routes of science
from the Arabic–Islamic world into Europe

II
Reception and Assimilation of Arab–Islamic Science in the West

[85] The first two—naturally quite modest—bibliographical studies devoted to books from the "Orient", known in the West through translations, appeared around the middle of the 19th century, at a time when Arab–Islamic science was looked upon with disdain rather than appreciation, as the interests of historians were occupied increasingly by the development of natural sciences in the West. These two works are *De auctorum graecorum versionibus et commentariis syriacis arabicis armeniacis persicisque commentatio* by Johann G. Wenrich (Leipzig 1842) and *Die Übersetzungen der arabischen Werke in das Lateinische seit dem 11. Jahrhundert* by Ferdinand Wüstenfeld (Göttingen 1877). For a long time, basically until today, interest in the question of the transfer of Arab–Islamic sciences—with the exception of certain subjects—was restricted to translators, works translated and extant manuscripts. Yet the issue of the impact of Arab–Islamic sciences as such in the West, be it through translations or through personal contacts, and the assessment of its significance rests mainly on the study of the scientific content of the Arabic (or Persian) writings and thus ultimately on the evaluation of the progress their authors made relative to their predecessors, in particular the Greeks. As shown above, Arabist research has meanwhile achieved remarkable results in the assessment of many surviving works so that a first evaluation in the context of the universal history of science was already feasible and even the question of the impact was addressed on a rudimentary level. The latter was largely limited to individual subjects or issues, only in a few areas was the question of influence treated on a larger scale.

A rare phenomenon in the history of science is the French Arabist Ernest Renan (1823–1892), who dealt with the issue of the reception of the Arab–Islamic sciences in the West in the field of philosophy. Writing his ingenious and admirable study *Averroès et l'Averroïsme*[1] in 1853, Renan had at his disposal only a small number of sources and he could hardly count on the support of his contemporaries. Nevertheless his work has remained valid to some extent until today. Starting with the assumption that in 4th/10th century Spain, Arabic was the common language of Muslims, Christians and Jews, he realised the role of the latter in the dissemination of Arab–Islamic philosophy in [86] Europe.[2] Renan maintained that secular Jewish literary culture in the Middle Ages was nothing but a mirror image of the Islamic culture,[3] just as Jewish philosophy since Maimonides (Ibn Maimūn) had, according to Renan, been nothing but a reflection of Arabic philosophy.[4] The entire school of Maimonides had remained true to the peripatetic tradition of Averroes (Ibn Rušd).[5] In general, so Renan, Jewish philosophy bore the traits of Arabic philosophy, even after the Jews had

[1] Third edition Paris 1867, reprint: Frankfurt, Institut für Geschichte der Arabisch–Islamischen Wissenschaften 1985.

[2] E. Renan, *Averroès et l'Averroïsme*, op. cit., p. 174.

[3] ibid, p. 173.

[4] ibid, p. 175.

[5] ibid, p. 182.

retreated to the Christian cities of Barcelona, Zaragoza, Narbonne, Montpellier, Lunel, Béziers, l'Argentière and Marseilles.[6] In connection with the translation of Arabic works into Hebrew, Renan made the interesting observation that Arabic words were retained or rendered by Hebrew words of the same root, even when these had a different meaning, hence the text was in a way emulated rather than translated.[7] After his masterly description of the process of reception and assimilation of Arabic philosophy in western Europe through Jewish mediation as well as direct translation into Latin, including how this caused hatred amongst the Dominicans and the opposition of Raymundus Lullus, Renan traces the reception of Ibn Rušd's philosophy in Italy from the beginning of the 13th century. Here too Renan, well-read and witty, draws a lively picture of the scholarly circles who, after three hundred years of studying the Arabic peripatetic teaching, had to endure the anti-Averroïsm reactions in the 16th century.

How deeply Arabic astronomy and astrology influenced the West was demonstrated best by the non-Arabist science-historian Pierre-Maurice-Marie Duhem[8] (1861–1916) in volumes 2 to 4 of his monumental *Le système du monde. Histoire des doctrines cosmologiques de Platon à Copernic.*[9] Although the great Arabist Carlo Alfonso Nallino in his *Al-Battānī sive Albatenii opus astronomicum*[10] had already paved the way for future research with invaluable hints, yet it is the results Duhem achieved through comparison of available Latin translations of Arabic works of astronomical–astrological content with European works written under the influence of the former, which allow us to comprehend how profound the impact of works translated from the Arabic was, not only on areas of Duhem's special interest, but far beyond, in the entire cultural history throughout Europe.

In the field of music and musical theory the question of the "Arabian influence" was addressed, fortunately, quite early-on in comprehensive studies. Not even a century had passed since the first surveys of "Arabian" music by R. G. Kiesewetter[11] and J. G. L. Kosegarten,[12] when the Spanish Arabist Julian Ribera y Tarragó in his *La música de las Cantigas*[13] produced a pioneering work [87] on the question of Arabian influences. In the first of the three parts of his book he deals with the history of Arab music in the Islamic world up to the 6th/12th century and in the second part with its history in Spain. The third part is devoted to the author's main interest, the question of the influence of Arab on Spanish music and on the European troubadours.[14] It is understandable that Ribera's ideas and results—particularly as regards the question of influences on Western polyphony in the Middle Ages—had their shortcomings, were inapt in many points and could not be left without contradiction.

Three years after the publication of Ribera's book, Henry George Farmer wrote his *Clues for the Arabian Influence on European Musical*

[6] E. Renan, *Averroès et l'Averroïsme*, op. cit., p. 184.

[7] ibid, p. 185.

[8] On him v. Donald G. Miller in: Dictionary of Scientific Biography, vol. 4, New York 1971, pp. 225–233.

[9] Completed before 1916, published in 10 volumes, Paris 1913–1959.

[10] Three volumes, Milan 1899–1907, reprint Hildesheim 1977.

[11] *Die Musik der Araber, nach Originalquellen dargestellt*, with a foreword by J. v. Hammer-Purgstall, Leipzig 1842, reprint Schaan (Liechtenstein) 1983.

[12] *Die moslemischen Schriftsteller über die Theorie der Musik*, in: Zeitschrift für die Kunde des Morgenlandes (Bonn) 5/1844/137–163.

[13] Published Madrid 1922, abridged English translation *Music in ancient Arabia and Spain* by Eleanor Hague and Marion Leffingwell, Stanford 1929, reprint New York 1970.

[14] A useful summary of the contents is to be found in Otto Ursprung, *Um die Frage nach dem arabischen bzw. maurischen Einfluß auf die abendländische Musik des Mittelalters*, in: Zeitschrift für Musikwissenschaft (Leipzig) 16/1934/129–141, 355–357, esp. 132–133.

Theory[15], which caused quite a stir.[16] The work was promptly criticised by the music historian Kathleen Schlesinger in *The Question of an Arabian Influence on Musical Theory.*[17] In 1929 Farmer's comprehensive study of Arab musical history, *A History of Arabian Music to the XIIIth Century*, and in 1930 his *Historical Facts for the Arabian Musical Influence* appeared in London. In the latter he discusses at length, inter alia, K. Schlesinger's criticism. Ignorant of those comprehensive more recent treatments of the question by Farmer, Otto Ursprung published a sharp response to Farmer's older works in 1934.[18]

Farmer's main topics and hypotheses, referring to Arabian influence and which encountered harsh criticism, are matters of notation and early polyphony, solmisation, musical instruments, lute tablature and metric modes. The discussion of many of these issues centred on the question of whether the new elements in music appearing from the 9th century in the West, go back to Græco-Byzantine or to Arab influences. Of course, Farmer did not deny the Greek basis of Arab musical theory, but he was convinced that the Arabs revised the inherited theories and developed them further. In 1976 two studies appeared on this subject in which Farmer's conclusions are discussed and elaborated upon. These are *Die Theorien zum arabischen Einfluß auf die europäische Musik des Mittelalters* by Eva Ruth Perkuhn[19] and *Zur Rolle der Araber in der Musikgeschichte des europäischen Mittelalters* by Eckhard Neubauer.[20] The author of the first study does not oppose the influence-theory in general, but she finds that "in the works on the problem of Arabian influence contributed by ethnomusicologists, methodological and theoretical questions are dealt with in passing, if at all."[21] Ribera and Farmer, "the main proponents of the Arabian theory" were "known to be more Arabists than ethnomusicologists" and "hardly acquainted" either with the "practice of Arab music" or with the "problems of cultural anthropology and [88] ethnomusicology".[22] Their approach met with harsh criticism[23] "on the part of music historians who opposed the Arabian hypothesis on emotional rather than factual grounds" and "found a ready field for attacks in such easily discernable theoretical flaws." According to Ms. Perkuhn, both Ribera and Farmer gave "little consideration to the process of transmission." Farmer however, "even went a step further narrowing himself down by excluding the ethnomusicological aspects, crucial for the research in 'oral' transmission and by limiting himself to musical instruments alone."[24] Hence she concludes that strictly speaking "the Arabian theory can only be established for the various aspects of music making in the European Middle Ages after research in Arab music culture itself has been thoroughly revised and conventional or dictionary wisdom has been confronted with ethnomusicological and cultural–anthropological considerations."[25]

The second[26] of the two works mentioned above was penned by an Arabist and music historian and provides us not only with an adequate assessment of H. G. Farmer's achievements but

[15] In: Journal of the Royal Asiatic Society 1925, pp. 61-80 (reprint in: The Science of Music in Islam, vol. 1, Frankfurt 1997, pp. 271-290).

[16] Farmer's approach was welcomed by Eugen Beichert in: Orientalistische Literaturzeitung (Leipzig) 29/1926/273–277.

[17] In: The Musical Standard (London) n.s. 25/1925/148–150, 160–162.

[18] *Um die Frage nach dem arabischen bzw. maurischen Einfluß*, op. cit.

[19] Published in Walldorf (Hesse, Germany).

[20] In: *Islam und Abendland. Geschichte und Gegenwart,* ed. by André Mercier, Bern and Frankfurt 1976, pp. 111–129.

[21] E. R. Perkuhn, op. cit. p. 232.

[22] ibid, p. 232.

[23] ibid, p. 233.

[24] ibid, p. 233.

[25] ibid, p. 236.

[26] E. Neubauer, *Zur Rolle der Araber,* op. cit., p. 118 ff.

beyond that also with results of more recent research: "In 1930 the musicologist Henry George Farmer summarised current theories on musical influences of the Arabs, put them in focus and added many results of his own research. His *Historical Facts for the Arabian Musical Influence* have encountered fierce hostility but have so far not been refuted." Issues discussed by Farmer taken up and elaborated upon here include "attempts to notate instrumental music, carried out both by the Arabs and in the European Middle Ages.[27] They are based on the use of the letters of the alphabet for the designation of scale degrees, as known by the ancient Greeks, and the use of lines for pitch notation, which appears to have originated in Middle Eastern late antiquity.[28] The Arabs wrote down melodies in letter notation and with certain cue syllables or numerals for durations and rhythm; and they did this earlier and more frequently than the few extant documents suggest. An alphabetic tabulature survives from the 10th century,[29] and the Arabic *Great Book of Songs* [*Kitāb al-Aġānī al-kabīr* by Abu l-Faraǧ al-Iṣfahānī] preserves a report which is to be dated at the beginning of the 9th century about Isḥāq al-Mauṣilī… It says that Isḥāq sent a new composition to one of his colleagues with written indications of all pitches, durations and phrasings. Thereupon the colleague sang the piece and he sang it correctly without ever hearing it.[30] At the beginning of the 11th century Avicenna [Ibn Sīnā] demanded that a song must not be learnt without first writing it down exactly, with pitches as well as lengths.[31] Most of the extant types of Arab notation refer to the lute [*ʿūd*]. [89] According to Notker Labeo (d. 1022) and others, the alphabetical notation in the West also originated among instrumentalists and was first used for the *lira* and the *rota*.[32] Hence it appears that both sides originally shared a common tradition. Yet when during Avicenna's lifetime new concepts of pitch notation were introduced almost at the same time and according to the same principles by Hermannus Contractus (d. 1054) in Byzantium, this rather obviously implies an Arabic model,[33] especially as Hermannus Contractus is known to have been acquainted with Arabic natural sciences."[34]

"A further step in the development leads us to Guido of Arezzo's (d. 1050) staff notation. He refers to his three to five parallel horizontal lines as 'imitation of the string'[35], and two of these lines are coloured: 'lustrous saffron is gleaming where the third tone has its place; the sixth, however,… glows in vermilion'.[36] While Guido's sources for what until today has been considered his own achievement remain obscure,[37] Arab practice of using coloured lute strings tuned to certain pitches offers at least a

[27] H. G. Farmer, *Historical Facts*, p. 83 ff., 304 ff.; E. Neubauer, op. cit., pp. 119,127.

[28] H. G. Farmer, *Historical Facts,* pp. 302 ff., 325 ff.; E. Neubauer, op. cit., pp. 119, 127.

[29] *Risālat Yaḥyā b. al-Munaǧǧim fi l-mūsīqī,* ed. Zakarīyāʾ Yūsuf, Cairo 1964, p. 45; E. Neubauer, op. cit., pp. 119, 127.

[30] Abu l-Faraǧ al-Iṣfahānī, *Kitāb al-Aġānī al-kabīr,* vol. 10, Cairo 1938, pp. 105–106; E. Neubauer, op. cit., pp. 119, 127.

[31] Abū ʿAlī Ibn Sīnā, *aš-Šifāʾ. ar-Riyāḍīyāt. 3. – Ǧawāmiʿ ʿilm al-mūsīqī,* ed. Zakarīyāʾ Yūsuf, 1956, p. 142; E. Neubauer, op. cit., pp. 119, 127.

[32] H. G. Farmer, *Historical Facts*, op. cit. p. 317; E. Neubauer, op. cit., pp. 119, 127.

[33] H. G. Farmer, *Historical Facts*, op. cit. pp. 36, 83 ff.; E. Jammers, *Gedanken und Beobachtungen zur Geschichte der Notenschriften*, in: Festschrift Walter Wiora, Kassel 1967, p. 199; E. Neubauer, op. cit., pp. 119,127.

[34] H. G. Farmer, *Historical Facts,* op. cit., p. 35; E. Neubauer, op. cit. pp. 119,127.

[35] H. Oesch, *Guido von Arezzo*, Bern 1954, p. 5; E. Neubauer, op. cit., pp. 119, 127.

[36] H. Oesch, op. cit.p. 6; E. Neubauer, op. cit., pp. 119, 127.

[37] O. Ursprung, *Um die Frage nach dem arabischen bzw. maurischen Einfluß*, op. cit., pp. 137–138, 356; E. Neubauer, op. cit., pp. 119–120, 127.

convincing explanation for the association of colour and string/line."

After commenting upon further points which had irritated Farmer's adversaries, Neubauer continues:[38] "We are on safe grounds again regarding the impact caused by the translation of Arabic texts. In the field of musical theory it is the impulses which the philosopher Abū Naṣr al-Fārābī (d. 950) gave through the Latin translation of his *Enumeration of Sciences* [*Iḥṣā' al-ʿulūm; De scientiis*][39]. In addition to the familiar division in *musica mundana, humana* and *instrumentalis,* in the middle of the 12th century the West became acquainted, through this treatise, with another distinction of *musica speculativa* and *activa*—a classification which is derived from the practice of the performing musician 'which can either be contemplative and exploring (speculative) or active'.[40] It was already known in Greek music theory and was now introduced in elaborated form to the mediæval literature where it brought about a significant 'enrichment of the subject matter' of theoretical reflections."[41]

"The translation of Arabic works on natural sciences and philosophy reached its peak in Spain during the 12th and 13th centuries. It is significant that their dissemination coincided with the foundation of the first European universities and largely dominated their curricula.[42] The writings of Avicenna were amongst the most prominent in this development, [90] including some parts of his *Kitāb aš-Šifā'* under the Latin title *Liber sufficientiæ.*"

"On the same route, via translations and university curricula—first in Spain, Italy and France—the West was also introduced to the highly developed theory and practice of Arab music therapy. The use of sounds and melodies for restraining emotions occupied an important position in the dietetics of Arab medicine. They had developed their lore from ancient Greek theory and Late Antiquity's practical experience; they knew that the Persians of the Sassanid period tried to cure melancholy with music and the post-Platonic ethos had far reaching influence… down to the association of lute strings with the fluids of the body."[43]

In the second half of the 20th century, Heinrich Schipperges earned merits with his numerous treatises and monographs on the reception and assimilation of Arabic-Islamic medicine. In full appreciation of the importance of his various articles, we shall focus here primarily on his two works dealing with our subject on a broader scale. In one of them, entitled *Ideologie und Historiographie des Arabismus,*[44] Schipperges was, as far as I am aware, the first to tackle the difficult task of assessing the reception and assimilation of Arab–Islamic sciences from the viewpoint of historiography. He begins with the time at which an awareness for the phenomenon had first arisen and traces its development up to the middle of the 20th century. In his comprehensive study Schipperges draws a clear picture of the antagonistic attitude prevalent from the 13th century towards knowledge adopted from the Arab–Islamic world. This in turn caused the current almost total lack of appreciation of this heritage, despite all attempts to do justice to its great importance. For Schipperges him-

[38] *Zur Rolle der Araber in der Musikgeschichte des europäischen Mittelalters*, op. cit., pp. 122–123.

[39] H. G. Farmer, *al-Fārābī's Arabic–Latin writings on music*, London 1934 (reprint: New York 1965 and: The Science of Music in Islam, vol. 1, Frankfurt 1997, pp. 463–533); E. A. Beichert, *Die Wissenschaft der Musik bei al-Fārābī*, Regensburg 1931, pp 24 ff.; E. Neubauer, *Zur Rolle der Araber*, pp.123, 128.

[40] v. G. Pietzsch, *Die Klassifikation der Musik von Boetius bis Vgolino von Orvieto*, Halle 1929 (reprint: Darmstadt 1968), p. 79; E. Neubauer, op. cit., pp. 123, 128.

[41] G. Pietzsch, op. cit. p. 78; E. Neubauer, op. cit., pp. 123, 128.

[42] H. Schipperges, *Einflüsse arabischer Wissenschaften auf die Entstehung der Universität,* in: Nova Acta Leopoldina (Halle) 27/1963/201–212; E. Neubauer, op. cit. pp., 123, 128.

[43] E. Neubauer, op. cit. p. 123.

[44] Wiesbaden 1961; supra, p. 2.

self Arabism is a "phenomenon that has exerted powerful influence over the centuries and still continues to do so and without which we will not understand the configuration of the modern world."[45]

The second of the two works, entitled *Die Assimilation der arabischen Medizin durch das lateinische Mittelalter*[46] was extremely helpful in our attempt to obtain the most realistic possible picture of the science-historic phenomenon of reception of Arab–Islamic science in the West and its impact. In this work Schipperges concentrates mainly on the question: "How did the reception of Arabic medicine in the Latin Middle Ages take place?"[47] Schipperges frequently uses the term "Graeco-Arabic" for the adopted medicine, meaning the one in the Arab–Islamic area based on the achievements of the Greek predecessors. After defining the subject he initially focusses on the period between the late 11th century and the end of the 13th century, a time when, according to his view, "Arabism" played an important role: "The reception of Graeco-Arabic medicine is considered only from the perspective of the Latin tradition; investigation stops with the translators and their work, it does not pursue the Arabic subject matter, but rather limits itself to the Latin manuscripts."[48] Schipperges believed it was his task "to question systematically the [91] current notions about the period of reception and thus ultimately the received image of mediaeval medicine in general."[49] With this goal in mind, he from the onset bypasses the discussion of medical matters and theory. Rather he pursues his aim on the basis of an historiographical survey "on "the judgement of the centuries on the question of the importance of Arabic–Latin translations for Western medicine".[50]

Schipperges assumes the process of reception began in 11th century Salerno in connection with the converted Arab and later monk of Monte Cassino, Constantinus Africanus (ca. 1015–1087), whom Karl Sudhoff[51] in 1930 had called "quite a providential character for the Western medicine of the Middle Ages." Apparently, Constantine hailed from Carthage and found his way to Salerno, after a thorough and multifarious study of sciences in Iraq and other countries—as reported by a Western source about 50 years after his death.[52] He carried dozens of Arabic medical books with him or had them sent later. With astounding diligence and probably also supported by members of his order, he succeeded in bringing into circulation more than 25 of those books in Latin. For the most part he claimed them as his own writings, a few he ascribed to Greek authorities. Most significant amongst these books was undoubtedly the extensive textbook of medicine by ʿAlī b. al-ʿAbbās al-Maǧūsī (d. last quarter of the 4th/10th century) dedicated to the Būyid prince ʿAḍudaddaula (r. 388/949–372/983) and entitled *Kāmil aṣ-ṣināʿa aṭ-ṭibbīya* or *al-Kunnāš al-malakī*.[53] This work, the Latin version of which bore a title, *Liber pantegni*, made up to sound

[45] H. Schipperges, *Ideologie und Historiographie des Arabismus*, op. cit. p. 5.

[46] Wiesbaden 1964.

[47] H. Schipperges, *Die Assimilation der arabischen Medizin*, op. cit. p. 2.

[48] ibid, p. 2.

[49] H. Schipperges, *Die Assimilation*... op. cit. p. 9.

[50] ibid, p. 9.

[51] *Konstantin der Afrikaner und die Medizinschule von Salerno*, in: Sudhoffs Archiv für Geschichte der Medizin (Leipzig) 23/1930/293–298, esp. p. 293 (reprint in: Islamic Medicine, vol. 43, pp. 179–184, esp. p. 179).

[52] v. Rudolf Creutz, *Der Arzt Constantinus Africanus von Montekassino. Sein Leben, sein Werk und seine Bedeutung für die mittelalterliche medizinische Wissenschaft,* in: Studien und Mitteilunger zur Geschichte des Benediktiner-Ordens und seiner Zweige (Munich) 47 (N. F. 16), 1929, pp. 1–44, esp. pp. 2–3 (reprint in: Islamic Medicine, vol. 43, pp. 197–240, esp. pp. 198–199).

[53] v. F. Sezgin, op. cit. vol. 3, pp. 320–322; facsimile edition of the book in 3 volumes Frankfurt, Institut für Geschichte der Arabisch–Islamischen Wissenschaften 1985.

Greek, was described by K. Sudhoff[54] as a work conceived like "cast from a mould… with such integral order and logical consistency, the like of which was not known in Greek medicine at all."

In 1127, exactly 40 years after Constantinus`s' death, Stephanus of Antioch translated the book into Latin a second time, but now under the name of its true author, ʿAlī b. al-ʿAbbās (*Liber completus artis medicinæ, qui dicitur regalis dispositio hali filii abbas…*).[55] This clearly contradicted the statement by Constantinus, who had introduced himself as the author of the book: "He, Constantine, inspired by the great benefit of this science, had at first examined various Latin works and found them inapt for teaching. Thereupon [92] he had taken recourse to the old Greek authors Hippocrates and Galenos, and of the more recent ones to Oribasius (of Byzantium), Alexander (of Tralles) and Paulus (of Ægina). He did not want to imitate Hippocrates, the excellent sovereign of the art, alone, as he found him often obscure and brief. Galen had written many extensive works… yet by their sheer magnitude discouraged many and consequently sixteen of his works were commonly used at most."[56] After Stephanus of Antioch, the second translator of the book, had accused Constantinus of plagiarism the latter's standing as an author was and still is judged on widely differing terms. He was despised as a"plagiarist", praised as a"magister orientis et occidentis novusque effulgens Hippocrates" and disparaged as a "mad monk". Finally, around the middle of the 19th century, a French historian of medicine finally demanded "that a congress of European scholars may erect a statue of Constantine at the gulf of Salerno or on the height of Monte-Cassino." In Julius Hirschberg's opinion, Constantine "the Arabic renegade and later monk of Monte Cassino was not yet languishing under the concept of intellectual property."[57] On the other hand, he was praised by Karl Sudhoff:[58] "Constantine loosened Salerno's tongue. Under his influence, stimulated by his gifts, it now created its own literature, the first in the Western Middle Ages in the field of medicine. And even if one has to cancel out many excessively laudatory phrases about him by another member of his order, Petrus Diaconus, yet one fact is undisputed: he became the preceptor of the medical West, the 'Magister Occidentis'!" Sudhoff[59] knew that Constantine brought into circulation various other Arabic medical books under his own name and he justifies this process thus: "no author's name is given in the case of purely Eastern writers to whom a number of minor works, such as a book on coitus, one on melancholy, one on forgetfulness and one on elephantiasis might belong as

[54] *Konstantin der Afrikaner*, op. cit. p. 295 (reprint: op. cit. p. 181).

[55] v. R. Creutz, *Der Arzt Constantinus Africanus von Montekassino,* op. cit. p. 24 (reprint op. cit. p. 220). This Stephanus came from Pisa, went to Syria later, spent some time in Antioch and brought medical books back to Pisa, amongst them apparently a complete copy of the book by ʿAlī b. al-ʿAbbās, cf. Charles Burnett, *Antioch as a link between Arabic and Latin culture in the twelfth and thirteenth centuries*, in: Occident et Proche-Orient: Contacts scientifiques au temps des Croisades. Actes du colloque de Louvain-la-Neuve, 24 et 25 mars 1997, ed. by I. Draelants, A. Tihon and B. van den Abeele [Turnhout:] Brepols 2000, pp. 1–19, esp. pp. 4–10 (infra p. 151 ff.).

[56] R. Creutz, *Der Arzt Constantinus Africanus von Montekassino*, op. cit. pp. 17–18 (reprint, op. cit. pp. 213–214).

[57] R. Creutz, *Der Arzt Constantinus Africanus von Montekassino*, op. cit. p. 1 (reprint, op. cit. p. 197); J. Hirschberg, *Über das älteste arabische Lehrbuch der Augenheilkunde*, in: Sitzungsberichte der Königlich Preußischen Akademie der Wissenschaften (Berlin), Jahrgang 1903, pp. 1080–1094, esp. p. 1088 (reprint in: Islamic Medicine, vol. 23, pp. 30–44, esp. p. 38).

[58] *Constantin der Afrikaner und die Medizinschule von Salerno,* op. cit. pp. 297–298 (reprint, op. cit. pp. 183–184).

[59] *Constantin, der erste Vermittler muslimischer Wissenschaft ins Abendland und die beiden Salernitaner Frühscholastiker Maurus und Urso, als Exponenten dieser Vermittlung*, in: Archeion (Rome and Paris) 14/1932/359–369, esp. p. 362 (reprint in: Islamic Medicine, vol. 43, pp. 185–195, esp. p. 188).

well, where only his [Constantine's] own name is mentioned as in the case of 'Viaticus' and 'Pantegni', which unjustly carry his name even though they are merely translations from the Arabic. Presumably he was hoping they would be accepted more readily by the scholarly circles of Salerno without the name of a Muslim author."

Against this reasoning by Sudhoff the objection can be raised that Constantine also presented the Latin version of the ophthalmology book (*Kitāb ʿAšr maqālāt*) by Ḥunain b. Isḥāq[60] (194/809–260/873) as his own work to his readers. The latter was however not a Muslim but Christian and Constantine could thus have mentioned his name and religion with pride. Yet his preface to this book reads in translation: "Those words that we have explained sufficiently in the books 'Pantegni' and 'Viaticus' about the eyes are all that was available in the Latin language, because at the time we did not yet know the present small volume [93] dealing with the eyes. And therefore I, Constantine, monk of Monte Cassino, have compiled this booklet for you, Johannes, in order that you may find [more]—if you find the teachings of those books insufficient—whatever you may want to learn about the causes of ophthalmology, i.e. about the nature of the eyes and their composition."[61]

It is surprising that Constantine on the one hand mentions the 'small volume' he used, thus giving himself away, yet on the other hand professes unambiguously to be its author. At any rate, this book on ophthalmology was considered his own achievement for more than 800 years until in 1903 J. Hirschberg was able to prove that it is in fact a translation of Ḥunain b. Isḥāq's book. This is all the more surprising because—as Hirschberg also has pointed out—Ḥunain's work circulated in the West for centuries in another Latin translation, this time as a work by Galen and with the name of one Demetrio as translator. Constantine's book "corresponds, however, most exactly with the so-called *Galeni de oculis liber a Demetrio translatus*. It contains neither one sentence more nor less, it has the same sequence of topics—it merely has a different division of the chapters and it concludes earlier than the latter, because the last section (the tenth *maqāla*) on eye ointments is missing."[62]

In order to shed light on the question of how Constantine dealt with his Arabic sources his *De melancholia* shall be mentioned as another example. That book, printed in 1536 as a work by Rufus (of Ephesos), in the manuscript tradition is attributed to Constantine, following his statement in the book's incipit: "I, Constantine, compiled this little book from many works of our most experienced doctors in that field, gathering excerpts of all that seemed excellent to me. We see that the celebrated physician Rufus has written a book on melancholy and in its first part said much about the symptoms of people with a melancholy disposition. This book is about the hypochondriac type of melancholy, but Rufus also touched upon and knew the other two types."[63]

This incipit can serve as an instructive example of Constantine's treatment of his Arabic sources. He replaced the name of the true author with his own, as shown by comparison with the incipit of the original.[64] Even if we gather more

[60] v. F. Sezgin, op. cit. vol. 3, pp. 247–256.

[61] Translated from *Der 'Liber de oculis' des Constantinus Africanus. Übersetzung und Kommentar* by Dominique Haefeli-Till, Zurich 1977, p. 22.

[62] J. Hirschberg, *Über das älteste arabische Lehrbuch der Augenheilkunde*, op. cit. p. 1088 (reprint, op. cit. p. 38); cf. F. Sezgin, op. cit. vol. 3, p. 252.

[63] R. Creutz and W. Creutz, *Die "Melancholia" bei Konstantinus Africanus und seinen Quellen. Eine historisch–psychiatrische Studie*, in: Archiv für Psychiatrie und Nervenkrankheiten (Berlin) 97/1932/244–269, esp. p. 261 (reprint in: Islamic Medicine, vol. 43, pp. 312–337, esp. p. 329).

[64] "This little book on the disease known as melancholy, viz. the sullen depression, was written by the physician Isḥāq b. ʿImrān as a memory aid for himself (in case of an eventual loss of memory, particularly approaching old age, which Plato used to call the mother of forgetful-

examples from Constantine's works, the picture we get remains the same. They are very free translations with arbitrary [94] omissions, doing away with the names of Arab doctors, particularly those of the real authors. Latin texts of this kind, written in 11th century Salerno were, in Schipperges' terms, the result of a "first wave of reception"[65] in the field of medicine. In his view "the elements of rational structure reveal a systematic organisation of the corpus."[66] In this respect I come to a different conclusion. The original writings of the corpus consisted of works commonly known in western North Africa. Constantine's selection was not by design but arbitrary. He took what he could collect without great effort, brought the Arabic writings to Salerno and made them, as far as possible, accessible in Latin with the help of the members of his order. No purposeful systematic work can be expected of him.

As far as Constantine's influence is concerned, Schipperges argues that he had "no strategic impact" on Western medicine. "It only had a preliminary influence on European schools in general, however important the Corpus Constantinum was to become for Salerno."[67] With this assessment Schipperges is right in so far as he compares this first wave of reception of medical works with the second wave coming via the Iberian peninsula. Yet the bearing of this 'preliminary' influence should not be underestimated. Especially as, with one single exception, these translations of more than twenty works were never replaced by better ones but remained in circulation as works by Constantine for centuries .

As far as Constantine's treatment of his models is concerned, Schipperges avoids calling him a plagiarist. He holds that for Constantine's achievement the common term of reception was unsuitable. It was, right from the beginning, rather a revision of foreign learning to a certain coherent end, viz. an intentional fusion (of the interpretation of doctrines for a wider public) and adaptation. For this, so Schipperges, the term assimilation should be used.[68] I, however, do not believe that the terms Schipperges suggests are apt to the way Constantine treats his originals. In my opinion, the latter's translations are nothing but a form of reception. Certainly Constantine's omission of the real authors of the works he translated was under no circumstances justified. It should be asked why he acted like this. In 1930 Hermann Lehmann[69] remarked in this context: "I do not see any other explanation but that he intended to exalt his standing in the university of Salerno." I would tend towards a more differentiated explanation according to which Constantine's plagiaristic treatment of his originals goes back to more than one factor:
1. The 13th century report on Constantine's decision to bring Arabic medical books to Salerno appears significant to me. It relates how Constantine asked a physician in Salerno whether they were "sufficiently equipped with medical literature in the Latin language, which could not be affirmed. One had acquired knowl-

ness) as also to the benefit of those interested amongst the friends of medicine and followers of philosophy. Isḥāq b. ʿImrān said: I have not found a satisfactory treatise on melancholy or a definite word about this disease in the writings of any of my precursors, the exception being a man from the lineage of predecessors called Rufus of Ephesus." Quoted, with slight changes, from the translation by Karl Garber, *Isḥāq ibn ʿImrān, Maqāla fī l-mālīḫūliyā (Abhandlung über die Melancholie) und Constantini Africani Libri duo de melancholia*, Hamburg [1977], p. 1; cf. the German translation by A. Bumm, *Die Identität der Abhandlungen des Isḥāḳ Ibn ʿAmrān und des Constantinus Africanus über die Melancholie*, München 1903, pp. 9–10.

[65] *Die Assimilation der arabischen Medizin*, op. cit. p. 50.

[66] ibid, p. 53.

[67] ibid, pp. 53–54.

[68] ibid, p. 52.

[69] *Die Arbeitsweise des Constantinus Africanus und des Johannes Afflacius im Verhältnis zueinander*, in: Archeion (Rome) 12/1930/272–281, esp. p. 280 (reprint in: Islamic Medicine, vol. 43, pp. 338–347, esp. p. 346).

edge through practical application of 'studio et exercitio' and used them."

"From that Constantine had understood his cultural mission, returned to Carthage… and again applied himself to medicine for three [95] years, also collecting plenty of Arabic medical textbooks,… had then embarked… was overtaken by a storm… which badly damaged his manuscript treasures… With the remainder of it he luckily reached Salerno in the end."[70]

The crucial point in this report appears to be that the medical pursuits of the monks in the monastery of Monte Cassino, above Salerno, who were joined by Constantine, are said to have been of a practical nature only and that the monks had little or no literary experience at least in the field of medicine. Consequently they could not be expected to be concerned by the uncertainty created by Constantine in the question of authorship of the books translated from the Arabic.

2. Constantine was far superior to the other members of his order in his knowledge of languages, comprehension of the subject and also in literary ability. The monks presumably treated him like a prince and he decided freely and without interference on questions of authorship.

3. That he conceals the names of Arab authors of the translated works and of Arabic sources cited therein in favour of the Greek elements seems to have had religious motives.[71]

Schipperges sees the beginning of the second phase of reception of Arabic medicine in the first half of the 12th century in Toledo which had been under Arab rule from 711 to 1085. Not without influences through sporadic translations of Arabic books[72] into Latin which had already begun in the 10th century on the Iberian peninsula, an intensive "reception of the Arabic Aristotle"[73] started in Toledo. The city not only offered a wealth of written documents of Arab–Islamic learning to the Christian conquerors but also "the suitable climate for extensive cultural exchange because of its linguistic and cultural disposition."[74] Schipperges calls the peripatetic encyclopaedia that reached the West with this wave of reception the 'new Aristotle'.[75] It was the *Kitāb aš-Šifāʾ* of Abū ʿAlī Ibn Sīnā (Avicenna, 980–1037), a revision of the Aristotelian Corpus.[76]

Schipperges considers an advanced stage of the translation process in Toledo as a third wave of reception of Arabic medicine in the West. It took place in the second half of the 12th century; its most eminent translator was Gerard of Cremona (ca. 1114–1187). Amongst the works of Abū Bakr ar-Rāzī[77] (Rhazes, 865–925) he translated the books *al-Kitāb al-Manṣūrī fi ṭ-ṭibb (Liber medicinalis ad Almansorem), Kitāb at-Taqsīm (Liber divisionis) and Kitāb al-Ǧadarī wa-l-ḥaṣba (De variolis et morbillis)*. "With this body of writings, a solid foundation was laid for pathology and therapy. The awe inspiring last work of Rhazes, *al-Ḥāwī* or *Continens* was not translated until a century later by Faraǧ ben Sālim"[78] and remained incomplete.

[96] Of greatest importance for the process of reception of Arab medicine in Toledo was the translation, also by Gerard of Cremona, of the *Kitāb al-Qānūn fi ṭ-ṭibb (Liber canonis de medicina)* by Abū ʿAlī Ibn Sīnā, which became the ultimate "codex of basic rules for a scientific medicine, including in the West".[79]

70 Karl Sudhoff, *Constantin, der erste Vermittler muslimischer Wissenschaft ins Abendland…* op. cit. pp. 360–361 (reprint: op. cit. pp. 186–187).

71 A number of recent studies on Constantinus Africanus were edited by Charles Burnett and Danielle Jacquart, *Constantine the African and ʿAlī ibn al-ʿAbbās al-Maǧūsī. The* Pantegni *and related texts*, Leiden etc. 1994.

72 H. Schipperges, *Die Assimilation der arabischen Medizin*, op. cit. p. 87.

73 ibid, pp 55 ff.

74 ibid, p. 56.

75 ibid, p. 56.

76 ibid, p. 58.

77 v. F. Sezgin, op. cit. vol. 3, pp. 274–294.

78 H. Schipperges, *Die Assimilation der arabischen Medizin,* op. cit. p. 93.

79 H. Schipperges, *Die Assimilation der arabischen Medizin,* op. cit. p. 93.

Mention should also be made here of the 30th chapter (on surgery) of the *at-Taṣrīf li-man ʿağiza ʿan at-taṣnīf*, a comprehensive textbook of medicine by Abu l-Qāsim Ḫalaf b. ʿAbbās az-Zahrāwī[80] (d. ca. 400/1010), also translated by Gerard of Cremona. This text, known in the West under the title *Chirurgia Albucasis* or *Tractatus de operatione manus*[81], has influenced surgery for centuries.

It should further be mentioned here that in the course of the Toledean vogue of medical translation, the "Introduction to Medicine" (*al-Mudḫal ila ṭ-ṭibb or Masāʾil fi ṭ-ṭibb li-l-mutaʿallimīn*) by Ḥunain b. Isḥāq[82] (809–973), which had already reached the West under the title *Ysagoge Iohannicii ad tegni Galieni*[83] in translation by Constantinus Africanus, was brought into circulation again, as *Liber introductorius in medicinam,* by one Marcus of Toledo. This work was amongst the medical manuals with the widest dissemination in Europe and was "read at all universities until well into the 17th century".[84]

In the second part of his book, devoted to "people and centres of assimilation," Schipperges attempts, at least regarding the 13th century, to shed light on the question as to what became of the Arabic books translated during the three waves of reception. "What role did those adopted and assimilated texts play in European medicine? In which ways and through what channels was the new learning incorporated into mediaeval therapeutics? Who were the exponents of these transfers, conflicts, codifications? What happened to these elements which, as Arabism in the wider sense, run through the late Middle Ages?"[85]

In order to answer these questions, Schipperges focuses on the "centres of assimilation" in France, England and Southern Italy. In Chartres, which had come in contact with Arabic natural sciences from about the turn of the 10th century, the 12th century brought about the acquaintance with Aristotle (Arabus) and with Arab astronomy and medicine.[86] After the re-conquest of the Spanish provinces, French schools started "the reception of Arabic learning from cultural centres under Arab influence. Early in the 12th century we encounter the first documents of a new scientific flourishing as a result of the contact with Arabic sciences in Southern France."[87]

"Towards the middle of the 12th century a centre of translation emerged in Toulouse. It was based on the French tradition and soon formed a bridge to the centres of learning in Spain."[88] The most important translators of the Toulouse school in the 12th century were Hermanus Dalmata and Robert of Chester. The books translated by them predominantly belong to the fields of astronomy, astrology and physics.

[97] "The school of Toulouse gained further prominence at the beginning of the 13th century after the Parisian edict prohibiting Aristotle had been passed in 1215, when it became a warrant of a continuing Aristotelian tradition; philosophy and natural sciences enjoyed special attention in this school. Even though Pope Innocence IV extended the edict to the university of Toulouse in 1245 and Urban IV renewed it in 1263, these ordinances no longer had any practical effect".[89]

In the French centres of mediation, Jewish scholars played an important role by translating Arabic works into Hebrew and Latin. In connection with these scholars, Schipperges points out two facts which are significant for both the history of culture and the history of science. Firstly, the workshops of the translators were closely

[80] v. F. Sezgin, op. cit. vol. 3, pp. 323–325.

[81] v. H. Schipperges, op. cit. p. 95.

[82] v. F. Sezgin, op. cit. vol. 3, pp. 247-256.

[83] v. H. Schipperges, *Die Assimilation der arabischen Medizin*, op. cit. pp. 33, 89.

[84] H. Schipperges, *Eine griechisch–arabische Einführung in die Medizin*, in: Deutsche medizinische Wochenschrift (Stuttgart) 87/1962/1675–1680, esp. p. 1675.

[85] H. Schipperges, *Die Assimilation der arabischen Medizin*, op. cit. p. 107.

[86] ibid, pp. 111–118.

[87] ibid, pp. 123–124.

[88] ibid, p. 124.

[89] ibid, pp. 126–127.

connected with the synagogues just like the madrasa to the mosque in Islamic culture, "a feature obviously in common with the Western institution of cathedral and monastery schools, and thus becoming a factor in the process of assimilation which must not be underestimated."[90] Secondly, the tolerance practised towards the schools in the French region and the Jewish translators active there is surprising, particularly considering that in 1241 Christians could be excommunicated if they saw Jewish doctors for treatment.[91]

In Paris, where in 1215 the study of Aristotle had been interdicted, the "new Aristotle" (Aristoteles Arabus) emerged victoriously from the middle of the 13th century in close association with the Latinised Ibn Sīnā (Avicenna).[92] In this connection it is worth noting that "around the middle of the 13th century… the rationalistic enlightenment of Averroëan philosophy was already being officially fought and condemned."[93]

"Averroës, the epitome of all heresy in the Middle Ages, was not taken as a historical figure but as a weapon in the conflicting opinions of the 13th century. He was attributed with saying what nobody dared to express in any literary form, yet he also declared war indiscriminately against all extreme systems. Only the theological exponents of the 14th century tried to rectify pure Averroïsm. Through him, Paris became the place of encounter with Arabised antiquity in its most extreme form."[94]

"For the Parisian school Averroës was, in the 13th century, more of a personification of speculative endeavours in medicine and natural sciences, whilst in practical medicine Avicenna maintained his central position there as well."[95]

After his overview of the French schools, Schipperges moves on to the encounter of the English with Arabism:[96] "Only one generation after Constantinus Africanus, a movement of scientific migration to the Arabised centres in southern Italy and Spain began in the Anglo-Saxon region which was to lead to a new and spontaneous wave of assimilation. Initially the subject was not medical science but the new mathematics and astronomy which, however, were to become very important for the foundation of the new perception of nature and thus also for the scientific foundations of medicine."

"In the Spanish–Frankish region or in southern Italy, the Anglo-Saxon pioneers had a particularly vivid encounter [98] with the new science resulting in a broad and creative assimilation of the new material. After returning to their old schools in England they realised how dusty those were. In the attempt to break open the crusts, the new sciences became the timber from which the 13th century centres of learning in England were fashioned."[97]

The most important representative of this movement was Adelard of Bath[98] (active 1116–1142). After long sojourns in centres of assimilation in France, Spain, Italy and Syria, he returned to England. Through translations from Arabic into Latin he made some important astronomical–astrological and mathematical books accessible in Europe.[99] He was possibly not only the

[90] H. Schipperges, *Die Assimilation*… op. cit. p. 128.

[91] ibid, p. 128.

[92] ibid, p. 129 ff.

[93] ibid, p. 136.

[94] ibid, pp. 137–138.

[95] ibid, p. 138.

[96] ibid, pp. 142 ff

[97] ibid, p. 143.

[98] About him v. Marshall Clagett in: Dictionary of Scientific Biography, vol. 1, New York 1970, pp. 61–64.

[99] v. *Adelard of Bath. An English scientist and Arabist of the early twelfth century*, ed. Charles Burnett, London 1987, including the following contributions: Margaret Gibson, *Adelard of Bath*; Alison Drew, *The* De eodem et diverso; Dafydd Evans, *Adelard on Falconry*; Charles Burnett and Louise Cochrane, *Adelard and the* Mappae clavicula; Gillain Evans, *A note on the* Regule abaci; André Allard, *L'époque d'Adelard et les chiffres arabes dans les manuscrits latins d'arithmétique*; Richard Lorch, *Some remarks on the Arabic–Latin Euclid*; Menso Folkerts, *Adelard's version of Euclid's* Elements; Charles Burnett, *Adelard, music and the quadrivium*; Raymond Mercier, *Astronomical tables in the twelfth century*; Em-

first Englishman but the first European to draw attention to the higher standard of Arab–Islamic sciences as compared to his own culture area (infra p. 138).[100] Amongst the other mediators who promoted the new knowledge of the natural sciences were Robertus de Losinga[101] who was the bishop of Hereford from 1079 to 1095 and, above all, Walcher of Malvern (d. 1135). This scholar, who was born in the Lorraine, visited Italy and came to England in 1091. He continued the process of assimilation in Adelard of Bath's spirit.[102] Moreover, in the second half of the 12th century Roger of Hereford founded a centre for Arabist studies in Malvern (Herefordshire).[103]

While dealing with the topic of Arabism and England we must not forget Robert of Chester. Although he was not an Englishman, he was, according to Schipperges, "in the direct tradition of Adelard of Bath." He received his education in Spain, worked at the school of Chartres and was on record in London from 1147. It was he who introduced Arabic algebra and alchemy in English schools.[104]

manuel Poulle, *Le traité de l'astrolabe d'Adelard de Bath;* Charles Burnett, *Adelard, Ergaphalau and the science of the stars*; John North, *Some Norman horoscopes*; Charles Burnett, *The writings of Adelard of Bath and closely associated works, together with the manuscripts in which they occur.*

[100] I would like to quote two passages from his *Quaestiones naturales* (Latin text ed. by M. Müller in: Beiträge zur Geschichte der Philosophie des Mittelalters, 31/1934/ esp. pp. 4 and 12) in which he addresses his nephew (English translation by Margaret Gibson, *Adelard of Bath,* op. cit. pp. 9 and 16): "We agreed that I would investigate the learning of the Arabs to the best of my ability; you on your part would master the unstable doctrines of the French" and "of course God rules the universe, but we may and should enquire into the natural world. The Arabs teach us that"; cf. Ch. Burnett, *Adelard of Bath, Conversations with his nephew*, Cambridge 1998, pp. 91, 97–99,103; H. Schipperges, *Die Assimilation der arabischen Medizin*, op. cit. p. 144.

[101] v. H. Schipperges, op. cit. pp. 149–150.

[102] ibid, p. 150.

[103] ibid, p. 150.

[104] ibid, pp. 151–152.

As an important representative of the Anglo-Saxon assimilation movement in the second half of the 12th century we encounter Daniel of Morley. After a stay in Toledo, where he had belonged to the circle of disciples around Gerard of Cremona,[105] he [99] returned home around 1177 with a large number of Arabic books. Whether he himself translated any of them we do not know. He exerted his influence in respect of Arabism more "through his personal communication"[106] than with his less successful *Liber de naturis inferiorum et superiorum*.[107]

Schipperges concludes his survey of the adoption of Arabic medicine in mediaeval Europe with a chapter on the currents of assimilation in Southern Italy. His valuable account draws a vivid picture of the situation in Sicily where, after the Arab conquest, "a natural link between the eastern and western cultures"[108] existed between the 9th and the 11th century. There the process of assimilation assumed a new quality through the person of Emperor Frederick II (r. 1212–1250). The emperor was "oriented towards the Arabic world by personal inclination and private encounters."[109] We shall return to the question of the nature and fruitfulness of these encounters in another context. Here we shall mention only the names of those scholars who took part in the assimilation process as cited by Schipperges. The most important figure in the circle of scholars around Frederick II was Michael Scotus. This philosopher, alchemist, as-

[105] v. Valentin Rose, *Ptolemäus und die Schule von Toledo* in: Hermes (Wiesbaden) 8/1874/327-349, esp. p. 330.

[106] H. Schipperges, *Die Assimilation der arabischen Medizin*, op. cit. p. 153.

[107] Ed. by Karl Sudhoff, *Daniels von Morley liber de naturis inferiorum et superiorum…* in: Archiv für die Geschichte der Naturwissenschaften und der Technik (Leipzig) 8/1917–18/1-40.

[108] H. Schipperges, *Die Assimilation der arabischen Medizin*, op. cit. p. 164.

[109] ibid, p. 166.

trologer and translator[110], who had been active in Toledo and Bologna, was called to Palermo by the Emperor.

To his "Sicilian period of translation Michael Scotus brought with him the spirit and the technique of the Spanish scientific tradition, particularly his proficient knowledge of the *new Aristotle* [Aristoteles Arabus], of medicine and music, of meteorology and alchemy."[111] We will have to pass over the works translated by him in Palermo, but I would like to draw attention to a tendency pointed out by Schipperges, viz. a body of corrupt translations using the name of Michael Scotus that betrays a sort of treatment of the sources that is detrimental to the history of science and that brought forth "innumerable unscientific and confused writings as part of the phenomenon of degeneration of manuscripts in the 14th and 15th centuries." Thus a manuscript in Paris states that Michael Scotus translated Averroes from the Greek.[112] An even more hideous example is furnished by "a 16th century manuscript which gives, following a fictitious Arabic text written in green, red and black, a Latin interpretation" One Michael Scotus of Prague reveals himself as the author of the purported Arabic text which under *secreta naturæ* introduces a profusion of superstitious ideas into medicine. Of significance for the history of science here, as pointed out by Schipperges, is the tendency to integrate astrology and magic into medicine and to propagate this lore with reference to Arabic authorities—a tendency that can be traced back to the early 16th century.[113]
Alluding once more to Heinrich Schipperges' commendable study of the process of reception and assimilation of 'Arabic' medicine, we may conclude with a quotation from his summary:[114]

"If we approach [100] the entire period of reception in terms of intensity regarding reception currents we firstly find a group of *initiators* like Constantinus Africanus, Adelard of Bath, Dominicus Gundissalinus; followed by *periods of incubation* such as in Salerno and Chartres, continuing and protracted, also in southern Italy; after that a further group of *promoting mediators* like Petrus Venerabilis, Raymundus of Toledo, Frederick II of Sicily; and finally a group of *realisators* either flocking around figures like Gerard of Cremona, Michael Scotus and Hermanus Dalmata or gaining constitutional importance in characters like Wilhelm of Conches or Petrus Hispanus."

"Regarding the assimilation movement we can distinguish: *a period of pure of reception* in which the material was acquired simply by registering it; such a period is discernible, however, only for mathematics and astronomy in the 10th and the 11th century; an *imitative phase of reception* in which the attempt was made to give an idea of Arabic science by means of compendia and compilations; *a productive phase* which, like in Chartres and Toledo, also interprets the new material creatively; and finally a *critical–synthetic assimilation* which got stuck in the attempts of the 13th and the 14th century."

Let us now turn to geography and cartography, being the only other fields of Arab–Islamic sciences for which the issue of reception and assimilation has already been treated fairly comprehensively. First of all, it is remarkable that none of the classical works of the local anthropogeography—a matter in which the Arab–Islamic world reached an impressive level—came to the notice of European cosmographers. For a long time I have been pondering over the question as to why none of these works were translated into Latin. Was there, perhaps, no interest in the subject? Even if we leave aside the classical geographical works of the 4th/10th century, the question remains as to why in the West the impact of al-Idrīsī's geography, composed in Sicily, was limited to its maps. Should we not consider

[110] G. Sarton, *Introduction to the history of science*, vol. 2, part 2, pp. 579–582
[111] H. Schipperges, *Die Assimilation der arabischen Medizin*, op. cit. p. 173.
[112] ibid, p. 175
[113] ibid, p. 176
[114] ibid, p. 187–188.

connecting the facts that the science of geography did not make any substantial progress in the West from the Middle Ages to the 16th century, and that the level of anthropogeography known from the Arab–Islamic area was reached only in the 19th century, with the fact that not a single Arabic textbook of this discipline was translated into Latin or indeed any other European language during either of the reception waves?

It seems that even those Arabic geographical works which, in translation, enjoyed a certain circulation on the Iberian peninsula, did not draw any attention in the neighbouring countries. This observation may be illustrated with an example. The geography of Andalusia by Abū Bakr Aḥmad b. Muḥammad b. Mūsā ar-Rāzī[115] (274/887 – 344/955) was rendered into Portuguese on the commission of the Portuguese King Denis (1279–1325) after the oral translation of the Muslim *Maese Mohamed* (al-muʿallim Muḥammad) by a monk named Gil Peres, who did not know Arabic. From this were derived a Castilian version and several adaptations, also in Castilian.[116] Even before its Portuguese translation, the book seems to have been well known in Spain. The anonymous author of the *Historia* or *Chronica Pseudo-Isidoriana*, who probably lived in the 12th century, took his description and the map of the Iberian peninsula from Aḥmad ar-Rāzī's book, as we know today from a study by the French mediaevalist [101] P. Gautier Dalché.[117] Dalché is inclined to see this as a "strict case of influence of Arab on Latin culture,"[118] but the influence seems to have been limited to the Iberian peninsula in this case.

[115] v. C. Brockelmann, op. cit. vol. 1, p. 150, suppl. vol. 1, p. 231.

[116] v. E. Lévi-Provençal, *La "Description de l'Espagne" d'Aḥmad al-Rāzī: Essai de reconstitution de l'original arabe et traduction française*, in: Al-Andalus (Madrid, Granada) 18/1953/51–108, esp. p. 52.

[117] *Notes sur la "Chronica Pseudo-Isidoriana,"* in: Anuario de estudios medievales (Barcelona) 14/1984/13–32.

[118] ibid, p. 14.

The oldest Arabic geographical work of a descriptive nature known to have reached Europe so far is a description of Africa, published by Gian Battista Ramusio around 1550 under the title *Della descrittione dell'Africa et delle cose notabili che ivi sono* in the collection *Navigationi et viaggi*; it was written by the North African al-Ḥasan b. Muḥammad al-Wazzān, who had been captured by Italians and was later baptised Giovanni Leo (Africanus). We have already discussed (supra, p. 77f.) how profoundly this book influenced Italian scholars of the 16th and the 17th century, with its maps as well as its excellent descriptions.

It is further surprising that the text—as opposed to the maps—of the above mentioned work by al-Idrīsī only became known late and in the form of a heavily abridged and almost mutilated edition printed in Rome in 1592; it was translated into Italian by B. Baldi in 1600 and into Latin by the two Maronites Gabriel Sionita and John Hesronita in 1619.[119] It is to be regretted that the Latin translation, without naming al-Idrīsī as the author, was erroneously brought in circulation as *Geographia Nubiensis* and was cited as such for a long time.

Even though Arabic anthropo–geography remained largely and for a long time unknown in Europe outside Spain, it seems established beyond doubt today that the mathematical geography and cartography of the Arab–Islamic world exerted a profound influence on their European successors from the 11th up to the 18th century.

As far as the mathematically oriented geography is concerned, we may say right away that the Ptolemaic geography, essentially consisting of a cartographic instruction manual and tables of coordinates comprising about 8000 localities, was not known in the Latin language area prior to the 15th century. Around the turn of the 13th to the 14th century, the Byzantine

[119] v. F. Sezgin, op. cit. vol. 11, p. 82; G. Oman in: Encyclopaedia of Islam. New edition vol. 3, Leiden 1971, p. 1033.

Maximos Planudes claims to have re-discovered the Greek original which had been considered lost. It was translated into Latin at the beginning of the 15th century by the Italian Jacopo Angeli (Jacobus Angelus).[120]

The basic work of mathematical geography *Taḥdīd nihāyāt al-amākin li-taṣḥīḥ masāfāt al-masākin* by Abu r-Raiḥān al-Bīrūnī (d. 440/1048), unfortunately did not reach the West. The West did, however, sporadically receive glimpses of the notions longitude and latitude and how they were determined in the days before al-Bīrūnī as early as in the 10th century through contact with Arabic Spain. In the 11th century this knowledge was deepened by the first translations of Arabic astronomical works in which those concepts and procedures occupy some room.

As early as in the 10th century some latitude bearings appear on the discs of the astrolabe attributed to Gerbert of Aurillac, later Pope Silvester II (d. 1003). [102] Three of the figures and lines inscribed refer to places in the Islamic world, the fourth latitude (42°) probably to Rome. This value too belonged to the latitudes registered (as 41° 40') on Arabic coordinate tables from the 9th century. Still, the works of Gerbert do not reveal any elements implying knowledge of mathematical geography.[121]

The oldest Latin work known to us that contains an imitative adoption of an Arabic table of the climata is *De compositione astrolabii* bearing the name of the Benedictine monk Hermannus Contractus (Hermann of Reichenau, 1013–1054) as its author.[122]

In the first half of the 12th century in which the process of the reception of Arab–Islamic sciences had progressed considerably, certain notions, definitions, procedures and data of mathematical geography reached the West through the translations of several Arabic handbooks on astronomy. Between 1120 and 1130 Adelard of Bath translated the astronomical tables of Muḥammad b. Mūsā al-H̱wārizmī (active during the al-Maʾmūn period, 198/813–218/833) in the version of Abu l-Qāsim Maslama b. Aḥmad al-Mağrīṭī (d. 398/1007). It was not least thanks to this that the use of the sine and of sine tables became known to the Latin world. What was even more important than this aid for a future work in mathematical geography was the four rules it contained for determining the latitude of any place. This also meant that the method first used by al-H̱wārizmī to calculate the altitude of the pole, i.e. the geographical latitude, on the basis of the upper and the lower culmination height of a circumpolar star, came to be known.[123] In passing, we may mention that the term algorithm and its derivations stem, in mutilated form, from the name of this mathematician and astronomer, al-H̱wārizmī,

Almost at the same time the Handbook of Astronomy by Muḥammad b. Ğābir al-Battānī (d. 317/929) reached the West, at first in the translation by Plato of Tivoli and somewhat later, translated once more, by the above mentioned Robert of Chester (Robertus Ketenensis). From the point of view of mathematical geography the book not only has important implications for spherical trigonometry and rules for determining degrees of latitude, but also contains a detailed table with geographical coordinates.[124]

From ca. 1130 onwards the oldest surviving handbook of Arabic astronomy, composed by Aḥmad b. Muḥammad b. Kaṯīr al-Farġānī (active between 218/833 and 247/861) reached the Latin world in the form of several different translations. Trough translations of this manual the West was presented with information more lucid than that of the two works mentioned above about the size of the Earth as deduced from the results of the measurement of one degree of the meridian at 56⅔ miles, as commissioned by Caliph al-

[120] v. F. Sezgin, op. cit. vol. 10, p. 272.

[121] ibid, vol. 10, p. 205.

[122] ibid, vol. 10, p. 206.

[123] ibid, vol. 10, p. 209.

[124] ibid, vol. 10, p. 209.

Ma'mūn, and knowledge of the division of the known world into seven climata. The book also provides a list of countries and towns which are arranged according to the seven climata, albeit without coordinates. Its profound influence in the 13th and 14th centuries on people like Robert Grosseteste, Albertus Magnus, Ristoro d'Arezzo and Dante Alighieri is well known. As late as 1464 Johannes Regiomontanus was still lecturing on al-Farġānī's book at the University of Padua.[125]

Consequently, the first compiled geographical table appeared in Europe a few years after the first translations of the [103] Arabic manuals of astronomy mentioned above. It is one of several tables to be found in the *Liber cursuum planetarum,* compiled from 1139 to 1140 by one Raymundo of Marseille. He omits the names of the translators of the works used by him and poses as the first translator of Arabic science.[126] Although he mentions the names of a number of Arab and European authorities, he most probably did not consult their works. On the other hand, he regards himself as an emulator of az-Zarqālī[127] and even reports how in 1139 he was involved in a discussion with two scholars whose tables were faulty. For our particular subject it is worth noting that one of the tables in this book contains the coordinates of 60 cities taken exclusively from Arabic sources. The data registered here show that even at that early date tables of coordinates from several Arabic works had evidently found their way (via Spain) to Europe. The compiler was of course hardly in the position to realise that these coordinates are of a heterogeneous nature and that some longitudes were reckoned from different prime meridians. On the whole, however, it is to be regretted that even the earliest Latin compilation of Arabic astronomy was bound for plagiarism.

The earliest attempt made in the Latin world to add some European localities to an existing table of coordinates appears to have occurred towards the end of the 12th century. Such an endeavour can be observed in the *Theorica planetarum* attributed to the well known translator of Arabic works, Gerard of Cremona (d. 1187). In it the author appends the coordinates of European towns in France, Italy and Spain, derived without exception from Arabic sources. These coordinates however bear no relation to reality. According to them Paris lies approximately 4° east of Rome (it is actually 9°50' to the west) and 16' south of Toulouse (in fact 5°15' north).[128]

In the 13th century, translations or adaptations of Arabic geographical tables and compilations based upon them, including descriptions of methods for taking coordinates, were so abundant that sooner or later attempts would be made to determine latitudes or longitudes in Europe outside Spain also. As far as we know, Ristoro d'Arezzo (d. after 1282) was the first Italian who, as a result of this development, aspired to calculate the latitude of a place astronomically. He determined the latitude of his hometown of Arezzo at 42°15', i.e. with an error of merely 1°13'.[129]

The highest stage of assimilation of Arab–Islamic mathematical geography achieved in Europe at that time was reached by the Franciscan Roger Bacon (1214–1292). His is the only known early attempt made in his area to design a map based on latitudes and longitudes. It is illuminating to read his complaint that with regard to the Latin world there was still no knowledge of latitudes and longitudes; this, he adds, could not be attained, even by competent scholars, unless there was support from the Pope, king or emperor.[130] Without purport-

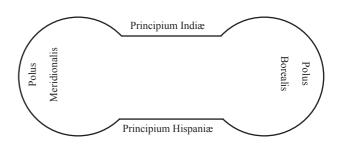
[125] v. F. Sezgin, op. cit. vol. 10, p. 210.

[126] v. Ch. H. Haskins, *Studies in the history of medieval science*, New York 1924, pp. 96–98; F. Sezgin, op. cit. vol. 10, p. 210

[127] v. P. Duhem, *Le système du monde*, vol. 3, Paris 1915, p. 208; F. Sezgin, op. cit. vol. 10, p. 210.

[128] F. Sezgin, op. cit. vol. 10, p. 212.

[129] ibid, vol. 10, p. 225.

[130] v. F. Sezgin, op. cit. vol. 10, p. 216.

ing to the reader that he had worked out the required latitudes and longitudes himself, he cites as his sources the *Qānūn* of astronomy (apparently az-Zarqālī's book in Latin translation) and the "Tables of Latitudes and Longitudes" [104] (presumably the *Toledan tables* and their emulations). Apart from the fact that the coordinates of the sources at his disposal were in no way sufficient to compile a world map or even a regional map, they also diverged substantially from each other because they were based on different prime meridians.

In addition to the prime meridian 11° west of Toledo, Roger Bacon also knew the one located 28°30' west of Toledo, which he calls *verum occidens*, the "true west"; he preferred this alternative to the one at 29° used by other Andalusian astronomers.[131] Yet the reason he gives for this preference shows that he did not know that this shift of the zero meridian to 17°30' west of the Canary Islands was the consequence of a substantial correction of longitudes between Toledo and Baghdad that Arab astronomers and geographers had achieved in the early 5th/11th century, and by which the representation of the Mediterranean was reduced to almost its true length.

Despite the insufficient number of available coordinates, Roger Bacon allegedly designed a map and presented a copy of it to the then Pope. Some scholars take the view that this map, now lost, was confined to the northern hemisphere of the Earth in globular projection. The question, of course, is on what basis Bacon should have worked if he lacked longitudes and latitudes of the Latin world, as he complained. Could the limited number of heterogeneous coordinates known to him have sufficed, without knowledge of the coastlines, for the cartographic delineation even of the non-Latin world? Are we not much rather required to assume that he had recourse to a map from the Arab–Islamic world, perhaps even the world map of the Ma'mūn geographers, which did in fact use globular projection? In this connection we should not forget the primitive map by Bacon's contemporary Albertus Magnus, which depicts only a few places in a crudely simplified, schematic form at odds with reality. We should also consider that a circular depiction of the surface of the Earth would have been in stark contrast to Roger Bacon's concept of the shape of the Earth. For he believed, on the one hand—probably miSunderstanding Averroës's (Ibn Rušd's) theory of the habitability of the southern hemisphere—that greater masses of water were present at both poles than in the centre of the Earth, where the waters extended from India in the east to Spain in the west; on the other hand, he leans on the notion of the existence of two places called Syene, one of which was said to be located in the Tropic of Cancer and the other on the Equator. Thus he arrived at the image of an Earth with two domes as depicted in his *Opus maius*:[132]

[105] The elementary procedures of mathematical geography as well as numeric figures which the West had received through multiple translations of al-Farġānī's Handbook of Astronomy

[131] Roger Bacon, *Opus maius*, ed. John H. Bridges, Oxford 1897, reprint Frankfurt 1964, vol. 1, p. 299; English translation Robert B. Burke, Philadelphia 1928, vol. 1, p. 319; P. Duhem, *Le système du monde*, op. cit. vol. 3, pp. 503–504; J. K. Wright, *Notes on the knowledge of latitude and longitude in the Middle Ages*, in: Isis 5/1923/75–98 (reprint in: Islamic Geography, vol. 23, pp. 113–136); F. Sezgin, op. cit. vol. 10, p. 217.

[132] Roger Bacon, *Opus maius*, op. cit. vol. 1, pp. 294, 310; Engl. trans., op. cit. vol. 1, pp. 315, 329; F. Sezgin, op. cit. vol. 10, pp. 218–219.

transpire in the works of Albertus Magnus (ca. 1200–1280). His *De cælo et mundo* shows that he was familiar with the measurement of the Earth commissioned by Caliph al-Maʾmūn. He knows the result, viz. that one degree of the meridian equals 56 ⅔ miles and he is also aware of the difference between the Arabic and the Latin mile.[133] With him we also encounter the degrees of the northern and southern fringes of the seven climata as we know them from the Maʾmūn geographers, from whom Albertus obviously took only full degrees, omitting the minutes.[134]

It is also instructive that in *Speculum astronomiæ,* ascribed to Albertus (or sometimes to Roger Bacon), the geographical longitude of Alexandria (51°20') is reduced in comparison to the value found in Ptolemy's Geography (60°30'), which reduction was assumed to stem from Ptolemy's *Canon*. It was, however, shown that this correction was indeed achieved only by the Maʾmūn geographers.[135]

From further details in the book, which overwhelmingly consists of a compilation of Arabic astrological and astronomical sources, it is evident that the author was familiar with the arc passing through Toledo as the zero meridian and with Arin as the starting point of the central meridian. At one point the author relates that he knows several astronomical tables, in which different cities such as Marseilles, London, Toulouse or Paris occur as prime meridians, stating that the latter two cities both have a longitude of 40°47' and a latitude of 49°10'. This statement is not alone in conveying the impression that in the second half of the 13th century the West did not yet have a clear conception of longitudes or differences in the longitudes of important cities.[136]

More obvious traces of the gradual adoption in the West of the basics of Arab mathematical geography are to be found in Dante Alighieri (1265–1321). Like his astronomy, his geography is also dependent on al-Farġānī's Handbook of Astronomy, which Dante had not only been able to use in both Latin translations, but also in an Italian version based on a French translation. Al-Farġānī's description of the seven climata was copied by Dante in every detail. Some longitudes and latitudes mentioned in the *Divine Comedy* are taken from Arab mathematical geography and show that here too he was dependant upon Arabic sources and that he was presumably using an Arabic map.[137]

The surviving European coordinate tables create the impression that the interest in this matter grew continuously from the beginning of the 14th century and that the circle of those interested grew steadily in course of time. Examining approximately one hundred of these tables during my work on the volumes *Mathematical Geography and Cartography in Islam and their Continuation in the Occident,* I came to conclusions concerning their origin and character that I would like to quote here:[138] Some of them are translations of Arabic originals, some are imitations of the *Toledan Tables* and some are extensions of the latter, when their time of origin dates back to before ca. 1250. From the last quarter of the 13th century onwards, [106] the extension of the tables produced by Arab and Arab–Spanish predecessors was intensified, especially in Spain, with regard to European locations. Most of the extended versions were brought into circulation under the title of the *Alfonsine Tables*. From the beginning of the 14th century onwards, some of the tables produced in the eastern part of the Islamic world were translated into Greek by Byzantine scholars. These tables seem to have found their way to Europe from the beginning of the 15th century onwards. The compiling work commenced in Europe in the 15th century. On the one hand, this consisted of collecting

[133] v. F. Sezgin, op. cit. vol. 10, p. 222.
[134] ibid, vol. 10, p. 223.
[135] ibid, vol. 10, p. 221.
[136] ibid, vol. 10, p. 221–222.
[137] ibid, vol. 10, p. 224.
[138] ibid, vol. 10, p. 222.

place names and their coordinates from existing sources, and, on the other, of adding new coordinates of European towns and cities, regardless of what their origin might have been. It would seem that some of the compilers did not fail to use additionally available maps as sources. And so, while the piecing together of heterogeneous coordinates which had been gained at various times and on the basis of various prime meridians was indeed confusing enough, the translation of the Ptolemaic *Geography* added a new element of confusion from the first quarter of the 15th century on. Besides Italy, this was especially the case in Germany, where a group of scholars, such as Regiomontanus and further disciples of the Nuremberg School based their work for around half a century or even somewhat longer on the Ptolemaic coordinates.[139]

With the Latin translation of Ptolemy's *Geography* (1406) from the Greek and especially after it had first been printed (1477), not only was its wealth of material available in Europe, but new difficulties also arose. After all, coordinates had been adopted from Arabic tables which in some cases already contained corrected Ptolemaic data and which were partly also made up of newly-acquired values. This included the corrected length of the axis of the Mediterranean of 53°, a prime meridian which had been shifted westwards into the Atlantic by 17°30', a different length of the Earth's circumference from that of Ptolemy, and the related length of the meridian degree of 56 ⅔ miles which was the valid figure among Arab geographers (in contrast to the 500 stadia of Poseidonios, which Ptolemy had adopted). All this made things difficult and confusing.[140]

One of the consequences of taking recourse to the Ptolemaic Geography was that some of the geographers in Europe now returned to using the length of 500 stadia which Ptolemaios had assumed and Poseidonios had estimated, according to which one degree equalled 62 ½ Roman miles rather than 56 ⅔ miles, as the Ma'mūn geographers had determined, a figure long known in Europe.[141]

After the confusion over the measurements of longitude, which lasted around one hundered years, several attempts were undertaken to measure the length of a meridian degree. The first such attempt was made by Jean Fernel. Fernel, a medical physician by profession, prided himself on having measured the distance between Paris and Amiens in 1525 by the number of revolutions of the wheels of a stagecoach, thereby measuring the length of a degree at 100.602 kilometres and a circumference of the Earth at 39,817.00 kilometres. Despite a number of factors of uncertainty, the fact that he achieved such an astonishingly good result already made his successor Willebrord Snellius sceptical; he thought that Fernel had "merely arbitrarily converted the result of the Arabic arc measure into geometrical steps, but had fooled his contemporaries with an act of deception." In reality, and despite this result, he stood "far [107] behind the Arabs who had served as a model as far as the measurement of longitude was concerned".[142]

Amongst further attempts to measure the length of a degree of the meridian, the one by the said Dutch scholar Willebrord Snellius (1580–1626) stood out with its high scientific standard. His method involved a kind of triangulation. But due to imprecise measurements of the polar altitudes at his two localities (from which their latitudes were calculated), the figure for the Earth's circumference he arrived at was too small.[143] It is presently not known to me since when modern geography has possessed a value for the

[139] F. Sezgin, op. cit. vol. 10, p. 230–231.

[140] ibid, vol. 10, p. 270.

[141] ibid, vol. 10, p. 280.

[142] O. Peschel, *Geschiche der Erdkunde bis auf Alexander von Humboldt und Carl Ritter*, 2nd improved ed. by S. Ruge, Munich 1877, p. 394: R. Wolf, *Geschichte der Astronomie*, Munich 1877, p. 169; F. Sezgin, op. cit. vol. 10, pp. 280–281.

[143] O. Peschel, op. cit., p. 396; F. Sezgin, op. cit. vol. 10, p. 382.

Earth's circumference more precise than that of the Maʾmūn geographers.

During the period when under the influence of the first printed edition of Ptolemy's *Geography* in Latin translation (1477) progress in the determination of longitudes and latitudes almost came to a halt in Germany and was completely interrupted in Italy,[144] the geographical work (*Taqwīm al-buldān*) by Abu l-Fidāʾ (d. 732/1331) with its comparative tables of coordinates was introduced in Europe.[145] The French orientalist Guillaume Postel, who from 1534 had spent a number of years in the Islamic world as an envoy and missionary, brought a copy of the book from İstanbul to Paris. He translated the parts he considered useful for his *Cosmographiæ compendium* (Basle 1561) and used these to compile tables for the purpose of correcting the bearings of places contained in European maps and charts, and especially in Venetian ones. In 1554 he brought the tables to the attention of the above mentioned Italian scholar, Gian Battista Ramusio, who was the editor of *Navigationi et viaggi* and who passed them on to the cartographer Giacomo Gastaldi. Perhaps these two scholars already had a Latin translation of Abu l-Fidā's book. Ramusio extracted a small selection of coordinates from it and expressed his delight about the discovery of the book with the words that it was "coming devinely to the light in our times." The high reputation of the book soon spread across Europe and in the English scholar Richard Hakluyt (d. 1616) kindled the desire to make it known to a larger public in a printed edition. To this end he tried to procure a manuscript copy of it from Syria, home of Abu l-Fidāʾ, in 1583.[146]

How well known Abu l-Fidāʾ's book was is also attested by the as yet inedited *Volume of Great and Rich Discoveries* by John Dee. It contains, inter alia, a report that around 1570 plans were in progress on whether one could reach Cape Tabin (Cape Chelyuskin) by sailing along the Arctic coast of Asia, i.e. whether East Asia could be reached by ship from the north. The two most eminent European cartographers of the time, Gerhard Mercator and Abraham Ortelius, disputed this while John Dee defended the theory of the navigability of that passage. He based his position on a detail from Abu l-Fidāʾ, viz. that northern China and the Asian coast were connected with Russia in the north and described this as "a record worthy to be printed in gold".[147]

Abu l-Fidāʾ's book was held in the highest esteem by the German scholar Wilhelm [108] Schickard (1592–1635). This versatile scholar had been commissioned with surveying the duchy of Württemberg and he desired to collect data on geographical bearings in a much wider scope in order to create the prerequisites for the mathematical representation of a large part of the old oikoumene. He was well aware of the inadequacy of the contemporary methods for determining geographical longitudes. In his search for reliable geographical bearings, Schickard happened upon the Latin translation of the abridged version of the above-mentioned book by al-Idrīsī (supra p. 38), but found the book of little help for his purposes.[148] After years of effort and correspondence, he received a manuscript of the *Taqwīm al-buldān* by Abu l-Fidāʾ on loan from the collection of the Viennese orientalist Sebastian Tengnagel in 1631. Schickard began a Latin translation of the book with commentary, but the work was left incomplete due to his untimely death. During the last four years of his life he preoccupied himself intensively with the book; what he managed to achieve is a verbatim Latin translation with many lacunae, accompanying face to face on double pages the

[144] J. Lelewel, *Géographie du moyen âge*, vol. 5, *Épilogue*, Paris 1857, p. 192; F. Sezgin, op. cit. vol. 10, p. 270.

[145] v. F. Sezgin, op. cit. vol. 11, p. 75 ff.

[146] ibid, vol. 11, pp. 79–80.

[147] ibid, vol. 11, p. 80.

[148] ibid, vol. 11, pp. 82–83.

Arabic text copied by himself; supplemented by commentary in marginal notes.

Schickard's attempts show that many significant Arabic sources on mathematical geography remained unknown to him as did the highly developed graticule of the old oikoumene created by Arab–Islamic geographers and astronomers from the turn of the 7th/13th century through the end of the 10th/16th century.[149]

Even in late 17th century Europe maps and tables of coordinates coexisted without any connection to each other. Thus Giambattista Riccioli (1598–1671), one of the well-known geographers of his time, commented upon his table containing about 2200 coordinates: "Almost innumerable are not only geographical world and regional maps but also the tables listing longitudes and latitudes of the more important places. However, they differ so greatly from one another, not only in the seconds, but often by whole degrees, so that this art seems to have lost all credibility, and one does not know whom to follow as the best guide in travelling across and describing the globe."[150]

The last quarter of the 17th century marks the beginning of a new era in the measurement of longitudinal differences. Galileo had already discovered the satellites of Jupiter with his telescope in 1610, but only now did it become feasible to work out their immersions and emersions for common use. Thus in determining geographical longitudes, the observation of lunar eclipses could be replaced by that of Jupiter's satellites. Credit for the ultimate success of this development is due to the astronomer Jean Dominique Cassini (1625–1712) in the context of the projects of the Academy of Sciences and its observatory founded in Paris by Louis XIV. At first the aim was a more accurate map of France, later the formidable task "of correcting the entire world map by proportional contraction or other revisions of the larger land masses."[151] One can easily imagine how difficult, costly and time-consuming the fulfillment of this task must have been even with regard to a small area of the Earth's surface. The results of a research expedition with the aim of correcting the longitudes of the Mediterranean made between 1693 and 1696 by Jean Matthieu de Chazelles (1657–1710), a pupil and junior [109] colleague of Cassini's, were confined to the determination of the longitudes and latitudes of Cairo, Alexandria and İstanbul, and of the latitudes of Larnaka, Damiette and the Dardanelles.[152] It was of course not to be expected that on the basis of coordinates gathered in such a way any substantial corrections of existing maps could be effected.

A comparison of the coordinates brought to Paris by Chazelles and the Arab–Islamic tables shows that, apart from the missing longitudes for Larnaka, Damiette and the Dardanelles, they are either almost identical or very close together.[153] It is therefore remarkable that after this enterprise the members of the Parisian Academy expressed the view that their assumptions "about the true longitude of the Mediterranean had at last been confirmed by Chazelles' measurements."[154] Of course they could not have known—as even today historiography of cartography still does not realize—that establishing the geographical coordinates of the Mediterranean region and further beyond took the joint efforts in the Arab–

[149] v. F. Sezgin, op. cit. vol. 11, p. 84.

[150] G. Riccioli, *Geographia et hydrographia reformata*, Venice 1672, pp. 388–409; Chr. Sandler, *Die Reformation der Kartographie um 1700*, Munich and Berlin 1905, p. 3a; F. Sezgin, op. cit. vol. 11, p. 138.

[151] Chr. Sandler, *Die Reformation der Kartographie*, op. cit. p. 66; F. Sezgin, op. cit. vol. 11, p. 140.

[152] v. *Regiæ Scientarum Academiæ historia*, Paris 1698, pp. 394, 395, 396; compare G. Delisle, *Détermination géographique de la situation et de l'étendue des différentes parties de la terre,* in: *Histoire de l'Académie Royale des Sciences*, vol. 1, Paris 1722, pp. 365–384, esp. pp. 366, 367; F. Sezgin, op. cit. vol. 11, p. 143.

[153] v. F. Sezgin, op. cit. vol. 11, p. 144.

[154] *Histoire de l'Académie Royale des Sciences*, vol. 2, Paris 1733, p. 142; Chr. Sandler, *Die Reformation der Kartographie*, op. cit. p. 9a; F. Sezgin, op. cit. vol. 11, p. 144.

Islamic world over a period of centuries and that these data alone rendered the design up of accurate maps feasible.

Summarising my assessment—based on my own research—of the contribution made by European astronomers in correcting the mathematical basis of the traditional image of the world between 1690 and 1725 I have to say that this contribution was not greater and in this initial brief phase could not be greater than verifying a series of longitudes of prominent points on the world map on the basis of observations of the Moons of Jupiter. This made it possible to primarily assess the degree of accuracy of the west–east extension of important sections of the world map and to draw possible consequences for cartography. As far as we can tell today, longitudes of Arab–Islamic maps calculated from the zero meridian running 28°30' west of Toledo prove to be several degrees too large. Thus the east coast of the Mediterranean is ca. 2°, Baghdad 3° to 3°30', Derbent (on the western shore of the Caspian Sea) ca. 4°, Delhi ca. 4° and the east coast of China ca. 5°–7° too far east. A high degree of precision was achieved between Baghdad and India. In this case the deviation of Arab–Islamic maps from modern maps lies below 1°.[155]

When, towards the end of the 17th century, French astronomers and geographers aspired to correct or proportionately reduce the conventional maps on the basis of newly established longitudes and latitudes, Jean-Baptiste Bourguignon d'Anville (1697–1782), perhaps the most important of all French geographers, chose a different approach. He himself informs us about this in his *Éclaircissemens géographiques sur la carte de l'Inde* (1753)[156] on the cartography of the Indian subcontinent. To correct the map of India and verify its graticule and distances, [110] d'Anville consulted the Arabic–Persian and Turkish works of geographical, historical and astronomical content that were known to him at that time. As far as we know he was the first European geographer of the 18th century who consulted and evaluated so many sources from the Arab–Islamic cultural sphere. The tables by Naṣīraddīn aṭ-Ṭūsī and Uluġ Beg did not escape his notice, their fame having spread in Europe since the edition and Latin translation by Johannes Gravius[157] of 1652. Unfortunately, however, d'Anville considered only the latitudes and not the longitudes of these and other Arab–Islamic tables. This was probably because he was unaware of the fact that the prime meridian in some tables was 28°30' west of Toledo or 17°30' west of the Canary Islands and thus about 34°50' west of Paris, rather than the 20° common with French cartographers since the last quarter of the 17th century. Consequently, the essential differences between the longitudes counted from the prime meridian passing through the Canary Islands and those counted from the newer prime meridian which had been shifted 28°30' west of Toledo meant nothing to him either. He knew the former from the translation of the comparative table of Abu l-Fidā'. The *Zīǧ*-work of Uluġ Beg is misleading in this respect as the headline of the coordinate-table erroneously states that the longitudes were counted from the Canary Islands.[158] As far as we are aware, it is James Rennell (1742–1830), who was the first European geographer to have recognised the great significance of the longitudes achieved by the "more modern" Arab–Islamic

[155] v. F. Sezgin, op. cit. vol. 10, pp. 160 ff. ; vol. 11, p. 155.

[156] Reprinted as Islamic Geography, vol. 255, Frankfurt 1997; v. F. Sezgin, vol. 10, p. 592.

[157] *Binæ tabulæ geographicæ, una Nassir Eddini Persæ, altera Ulug Beigi Tatari*, London 1652 (reprint in: Islamic Mathematics and Astronomy, vol. 50, pp. 1–79).

[158] We must consider this a slip. Roger Bacon already knew the prime meridian that had been shifted far to the west (supra p. 43); on the Ottoman side, I cite Muṣṭafā b. ʿAlī ar-Rūmī (d. 979/1571) who in the preface to his table compiled in 930/1524 mentions the prime meridian shifted to the west (v. F. Sezgin, op. cit. vol. 10, p. 186).

scholars, at least for the regions between Aleppo and Delhi (infra, p. 111 ff.)[159]

Since d'Anville was unable to come to terms with the longitudes known to him, he based his work on distances given in the Arabic–Persian and Turkish works of geography and history, the book by Abu l-Fidā' being his most frequently used Arabic source.[160] Through this book which he used in translation, d'Anville obtained data from works which were not accessible to him in translations or which were not extant. He also made use of quotes by Abu l-Fidā' from books not directly belonging to the field of mathematical geography but which covered areas of itinerary or topographical significance. It was indeed the works of Abu l-Fidā' and al-Idrīsī which he was able to use almost exclusively in his treatment of the map of China.

D'Anville's expectations regarding the accuracy of the latitudinal data contained in the "tables orientaux" and their validity for large expanses of the Earth surface, even beyond the Indian subcontinent, seem to have been rather high. Thus he comments on the position of the pronounced point Kambaya on the west coast of India as follows: "A translation which I possess from the book by Abu l-Fidā' registers the latitude of Kambaya in accordance with al-Bīrūnī as 22°20' which corresponds to the map but for an insignificant difference."[161] Incidentally, the name of al-Bīrūnī and his major work on astronomy, *al-Qānūn al-Masʿūdī* was to my knowledge first mentioned in Europe by d'Anville .

[111] After D'Anville, James Rennell, the eminent—perhaps the most eminent—English geographer, took up the task of verifying the cartographic depiction of the Indian subcontinent as known in Europe in the 1780s and aimed to improve it as far as possible on the basis of his own work. He took up work during his stay in eastern India in his capacity as Surveyor General of the British East India Company from 1763 to 1777. During the work on his project and especially in the course of the preparation of the accompanying text to the second edition of his map of India under the title *Memoir of a map of Hindoostan or the Mogul Empire* (London 1793)[162] between 1783 and 1792, he came to realise the importance of local sources. Amongst his numerous Arabic, Persian and Turkish sources, the *Āʾīn-i Akbarī* by the great historian and geographer of the Mogul Empire, Abu l-Faḍl al-ʿAllāmī (d. 1011/1602) assumes a pivotal position.

In his intention to depict India as realistically as possible on the basis of maps which had been produced over the past three hundred years, and to render the country interior as accurately as possible with the help of existing sectional maps and itineraries, the *Āʾīn-i Akbarī* was indisputably a source of the first order. It provided the most reliable means of verifying information pertaining to the eleven provinces above the Dekkan, because it not only provided extensive geographical descriptions and distances of routes, but also, and in particular, longitudes and latitudes.[163]

Moreover, Rennell—like his predecessor d'Anville—also had the modern values for the longitudes of a small number of landmarks in India at his disposal. These had been determined by observation of the Jupiter satellites. When working on the map of India, he made the capital Delhi (not Greenwich) the starting point for further calculations of distance. Besides the *Āʾīn-i Akbarī,* he also relied on the tables of Naṣīraddīn aṭ-Ṭūsī and Uluġ Beg, but he too erroneously believed that the longitudes in those tables had been calculated on the basis of a prime meridian which passed through the Canary islands, resulting in values that were more than 20° too great. Yet, since he calculated the longitudes backwards from Delhi, he became convinced that

[159] F. Sezgin, op. cit. vol. 10, p. 596.
[160] ibid vol. 10, pp. 596–597.
[161] ibid vol. 10, pp. 597-598.
[162] Reprint: Islamic Geography vols. 260–261, Frankfurt 1997.
[163] F. Sezgin, op. cit. vol. 10, pp. 604–605.

they were sufficient for his purposes. For the evaluation of those longitudes from west to east, he found a way to reckon them by their differences from cities in the west rather than from a prime meridian.[164] The manner in which Rennell based his design of the graticules for maps he revised on Arab–Islamic coordinate tables can be illustrated with an example: "Samarcand, according to the tables of Ulug Beig, is 99°16' east of the Fortunate Islands [the Canaries; as mentioned above, the shifted prime meridian 28°30' west of Toledo escaped him]; and Aleppo, in the same tables, is 72°10': that is, Samarcand is 27°6'E of Aleppo; and this last, being 37°09'E of Greenwich (by the latest determination of the French Academy, 34°49'E of Paris), Samarcand should be in 64°15' east of Greenwich. If we reckon it from Casbin (Qazwīn), which, according to M. Beauchamp's [Joseph Beauchamp, the astronomer 1752–1801] observation, is 49°33'E of Greenwich; and by Ulug Beig, 14°16' west of Samarcand; the latter, by this calculation, will be in 63°49': or 26 minutes farther west, than if reckoned from Aleppo. But having with much labour investigated the particulars of the distance between Casbin and Samarcand, and having compared them with the intermediate longitudes and latitudes recorded in the Oriental tables [112] I am inclined to adopt 64°15', for the longitude of Samarcand. Its latitude, taken with the famous quadrant of Ulug Beig, is 39°37' and some odd seconds."[165]

Rennell first tries to establish the longitude of Samarqand (99°16' in Uluġ Beg's table) as reckoned from Greenwich. Since he does not know the real prime meridian, he takes the longitude of Aleppo after Uluġ Beg (72°10') and 37°09', as taken with the latest method of observing the Jupiter satellites. By adding the longitudinal difference of both cities after Uluġ Beg to the longitude of Aleppo after the modern method, he obtains the longitude of Samarqand (99°16' −72°10' +37°09' =64°15'). In a second approximation he proceeds likewise, using the longitudinal difference between Qazwīn and Samarqand. If Rennell had known that the prime meridian on his Arabic–Persian tables was 28°30' west of Toledo (and thus 32°30' west of Greenwich) he could have calculated the longitude of Samarqand easily by the subtraction 99°16'−32°30'=66°46'.

Numerous other examples could be cited to show how Rennell, in revising the map of India and the territories to the north of it, in order to obtain as accurate coordinates as possible relied on the tables of Arab–Islamic astronomers and geographers, on the few bearings established by his European contemporaries and on distances given in parasangs or *qoss* (1 *qoss* = ca. 3 km) which he found in his sources. That the working material which he used were maps mostly based on originals from the Arab–Islamic world, shall be discussed later.

Finally I would like to quote Rennel's own words regarding the importance of geographical tables from the Arab–Islamic culture sphere for European geographers of the 18th century in verifying the accuracy of available graduaded maps: "Had Ptolemy lived in the present times, he might have expressed his wonder, that, considering the advantages *we* possess, *our* maps of Asia should be so incorrect; when the tables of Abulfeda, Nasereddin, and Ulug Beig, and the History of Timur, by Sherefeddin, have been so long amongst us, in an European language."[166]

I now turn to the question of the influence that Arab–Islamic geography exerted on Occidental geography through its maps. To my knowledge, Joachim Lelewel, an historian of geography and also a capable Arabist, was the first to address the question of the origin of those maps which, from the turn of the 13th to the 14th century, de-

[164] v. F. Sezgin, op. cit. vol. 10, p. 608.

[165] J. Rennell, *Memoir of a map of Hindoostan or the Mogul Empire*, London 1793 (reprint: Islamic Geography, vol. 260), pp. 191–192; F. Sezgin, op. cit. vol. 10, p. 609.

[166] J. Rennell, *Memoir*, op. cit. vol. 1, p. 199; F. Sezgin, op. cit. vol. 10, p. 610.

lineated the shape of the Mediterranean (often along with the Black Sea) almost perfectly. In Lelewel's view, these maps, usually referred to as nautical charts and, in the course of time, also as portolan charts, were originally based on a graticule established by means of geographical coordinates, the same graticule that was also the basis of further developments. Lelewel assumes it was created by "the Sicilian geographers" (between 1139 and 1154) improving upon the material inherited from Arab geographers and their Greek predecessors in the form of al-Idrīsī's geography and maps.[167] The debates [113] on the origin of the portolan charts which broke out afterwards, continue even today and views are often diametrically opposed to another.[168] Arabists, independent of Lelewel, have occasionally expressed the view that these maps were derived from those of al-Idrīsī (1154 ce).[169] Their efforts have however hardly been noticed by the vast majority of non-Arabist scholars. The reasons why this majority would not recognise or acknowledge the dependence of the maps on Arabic originals are many. Despite all efforts on the part of historical research in natural science to set this straight, a stubborn approach still persists to see the inherited knowledge of humankind only from an Eurocentric point of view. The clarity achieved by research in the history of science about the tremendous progress made by sciences in the Arabic-Islamic world—which, at the time when those almost perfect maps emerged, had already reached a very high stage in its development—was unfortunately neglected due to such preconceptions. It was a time that—in terms of history of science—falls in the period of reception and assimilation of Arab–Islamic sciences in Europe, when Europeans were acquiring new knowledge.

At first no significant evidence supporting the view that the so-called portolan charts were based on Arabic originals was at the disposal of Arabists. Moreover, hardly any attempt was made by Arabists to give an overview of Arab–Islamic cartography based on mathematical–astronomical principles and thus to instigate a discussion on its impact in the context of the process of reception and assimilation of Arab–Islamic science in the West. The motive for this passive attitude amongst Arabists was not so much the lack of convincing cartographic material but rather the notion which had imperceptibly become axiomatic in the West during the 19th and 20th century that the concrete cartographic representation of the Old World and its elaboration from the 13th century was a product of the western world and that it could not be otherwise. Like most of his contemporaries, the author of these lines was also conditioned by school and conventional wisdom in favour of this notion. When I consider it unjustified, historically unfounded and even absurd today, then I was led to this perception gradually and only in the last couple of years after long occupation with the subject; and in the beginning I had the good luck to happen upon the world map of the geographers of Caliph al-Maʾmūn (r. 198/813–218/833). The results of my research were published in 2000 under the title *Mathematische Geographie und Kartographie im Islam und ihr Fortleben im Abendland* as volumes 10 to 12 of the *Geschichte des arabischen Schrifttums*.[170] Some of the reasons that caused me to revise the received notion, which I myself carried around for half a century too, I shall discuss here because they are relevant for the question of the reception of Arab–Islamic maps in the West.

According to present knowledge, the oldest map originating in Europe in which traces of Arab influence are recognisable was made

[167] J. Lelewel, *Géographie du moyen âge*, op. cit. vol. 1, introduction pp. lxxxix–lxxx, vol. 2, p. 17; F. Sezgin, op. cit. vol. 10, p. 289.

[168] v. F. Sezgin, op. cit. vol. 10, pp. 285–300.

[169] ibid, vol. 10, pp. 300–310.

[170] Engl. transl. entitled *Mathematical Geography and Cartography in Islam and their Continuation in the Occident*, 2 vols., Frankfurt 2005–2007

by a Jewish apostate known by his christian name Petrus Alphonsus. It is a schematic chart of the world included in a little astronomy book he wrote around 1110 CE. The map is southern-oriented as was the Arab custom and shows the Arabic division in seven climates and the name of the city of Aren (Arin).[171] [114] Clues pointing to an Arab influence can also be found in the famous world map by John of Wallingford (d. 1258).[172]

One world map to which insufficient attention was paid by history of cartography appeared in the *Livres dou Tresor* (ca. 1265) by the Italian scholar Brunetto Latini,[173] interestingly without any specific reference to the text.[174] Its configuration, the delineation of oceans, mountains and rivers and the shape of the continents cause us to assume a model in the tradition of the world maps of the Ma'mūn geographers and al-Idrīsī, but already showing some further development regarding the shape of the Mediterranean, the Black Sea and Asia Minor. The image of the world as depicted in this map, preserved in Brunetto Latini's work—as a whole and in detail—must have been perceived as entirely new and strange in the non-Spanish West, as can be shown by a comparison with all other surviving European world maps of the 13th century. A comparison of this map with the depiction of the oikoumene by Latini's contemporary Albertus Magnus[175](d. 1280) or also in the world map of Petrus de Alliaco[176] (1410), active in the 14th century, would alone suffice to show how unusual this depiction must have been for the West, leaving aside that the maps by Albertus Magnus and Petrus de Alliaco also betray traces of Arabic astronomical–cosmographical sources.

The second oldest world map known to us that displays a striking similarity with the Ma'mūn and Idrīsī maps dates from around 1320. It bears the names of Marino Sanuto and Petrus Vesconte as authors. In ignorance of the Ma'mūn map, recent research has related this world map directly and solely to the al-Idrīsī map.[177]

The world map by Sanuto and Vesconte with all its versions is commonly grouped with the so-called portolan charts. The question of the latter's origin has been debated since ca. 1850 and answered in various ways. We are of the opinion that these maps at their time represented the latest stage of development in the history of cartography, accomplished by humankind as a whole—a development which had been dominated for the past five hundred years by the Arab–Islamic world, and which was to be dominated by it for another three hundred years, viz. from around 800 until 1600 CE.

The reasons for my conviction that the remarkable accuracy of the coastlines and the longi-

[171] v. C. R. Beazley, *The Dawn of Modern Geography,* vol. 2, London 1897, pp. 575–576; C. H. Haskins, *Studies in the History of Mediaeval Science*, New York 1924, pp. 113–119; R. Mercier, *Astronomical Tables in the Twelfth Century*, in: *Adelard of Bath. An English Scientist and Arabist of the Early Twelfth Century*, ed. Ch. Burnett, London 1987, pp. 95–96; F. Sezgin, op. cit. vol. 10, pp. 207–208; vol. 12, map 51, p. 110.

[172] A.-D. von den Brincken, *Mappa mundi und Chronographia. Studien zur imago mundi des abendländischen Mittelalters* in: Deutsches Archiv zur Erforschung des Mittelalters (Cologne and Graz) 24/1968/118–186, esp. pp. 148-149; F. Sezgin, op. cit. vol. 10, pp. 208, 326.

[173] v. F. Sezgin, op. cit. vol. 12, map 55, p. 114.

[174] A.-D. von den Brincken, *Die kartographische Darstellung Nordeuropas durch italienische und mallorquinische Portolanzeichner im 14. und in der ersten Hälfte des 15. Jahrhunderts*, in: Hansische Geschichtsblätter (Cologne and Graz) 92/1974/45–58; F. Sezgin, op. cit. vol. 10, pp. 223, 327–331.

[175] v. F. Sezgin, op. cit. vol. 10, pp. 220-223, vol. 12, map 53, p. 111.

[176] ibid, vol. 10, p. 216, vol. 12, map 54, p. 111.

[177] v. K. Miller, *Mappae arabicae*, vol. 1, Stuttgart 1926 (reprint: Islamic Geography, vol. 240) p. 51; T. Lewicki, *Marino Sanudos Mappa mundi (1321) und die runde Weltkarte von Idrīsī (1154)*, in: Rocznik Orientalistyczny (Warsaw) 38/1976/169–195; Fr. Wawrik, *Die islamische Kartographie des Mittelalters*, in: *Kultur des Islam*, Referate einer Vortragsreihe an der Österreichischen Nationalbibliothek, 16.–18. Juni 1980, ed. by O. Mazal, Vienna 1981, pp. 135–156, esp. pp. 152–153; F. Sezgin, op. cit. vol. 10, pp. 291, 293–294.

tudinal proportions in the larger part of the so-called portolan charts was achieved during the Arab–Islamic period of the history of cartography shall be explained later, for the moment I would like to refer only to some of the indirect arguments presented in the first part of this introduction [115] (supra p. 50 ff.); right now I shall briefly introduce the three surviving maps, each of which marks an important stage in the development prior to 1300 CE.

First, the world map of the geographers of Caliph al-Ma'mūn from the first quarter of the 3rd/9th century. A copy dated 740/1340 certainly fails to reproduce the original in all its splendour (infra III, 24), yet it and the map reconstructed after the surviving original coordinate tables (infra III, 25) show that this important work represents one of the defining stages in the universal history of cartography. The map is based on the one by Marinus (1st half of the 2nd century CE), on the *Geography* of Ptolemy (2nd half of the 2nd century CE) and on the results of the measurements and surveys made by a large group of scholars commissioned by the Caliph. It goes without saying that, in the first attempt at correcting and completing the inherited picture of the world, they were confined to gradual, if considerable, improvements. Their most striking contribution to the new world map consists in the following innovations which became pivotal for subsequent developments. Foremost, the Ma'mūn geographers conceived the oikoumene as surrounded by water and Africa as circumnavigable in the South, as opposed to Marinus's and Ptolemy's assumption of one single, connected continent in which the Indian Ocean forms a land-locked sea. Moreover, the Ma'mūn geographers reduced the excessive longitudinal extension of the Mediterranean in Ptolemy from 63° to 52° or 53° and made certain corrections in its cartographic depiction.

The next map, representing a further stage in the development, is the one by al-Idrīsī dating from 549/1154 (infra III, 26ff). It is established today that al-Idrīsī must have had the world map of the Ma'mūn geographers as a model and not, as was often claimed,[178] the one by Ptolemy (which most probably never existed). Despite certain drawbacks compared to the Ma'mūn map, al-Idrīsī's world map shows a better delineation of the Mediterranean, of Europe, and particularly of Central, North and North-East Asia. These advances, made in the course of the roughly 325 years since the Ma'mūn map, demonstrate that there was a lively development—especially regarding Asia—in the cartographic depiction of the Earth surface.

One of the surviving cartographic documents for the third stage of the development on the way to the so-called portolan charts is an Arabic–Maghribi map which depicts the coastlines of the western quarter of the Mediterranean with all the islands, the west coasts from Gibraltar up to northern France and parts of the English and Irish coast almost perfectly.[179] With a passing reference to the Chinese world map, the one by Naṣīraddīn aṭ-Ṭūsī and the didactic scheme of the Mediterranean and the Black Sea by Quṭbaddīn aš-Šīrāzī, all mentioned above (p. 49) and suited to support the notion sketched here regarding the stages of development of cartography in the Arab–Islamic world preceding the so-called portolan charts which appeared in Europe around 1300, we shall give some examples of the simultaneously created mathematical–astronomical basis for this development as well. In the first place, we shall consider the length of the great axis of the Mediterranean and the differences in longitude between some of its important coastal cities.

[178] v. e.g., M.A.P. d'Avezac, *Coup d'œil sur la projection des cartes de géographie*, in: Bulletin de la Société de Géographie (Paris) 5e série, 5/1863/257–485, esp. pp. 293–294; F. Sezgin, op. cit. vol. 10, p. 286.

[179] v. F. Sezgin, op. cit. vol. 11, pp. 27–31, vol. 12, map 35, p. 74.

The values are taken from tables featuring the extensive corrections regarding the longitudes of cities between Toledo and Baghdad which had been made from the first half [116] of the 5th/11th century. Thus the longitudinal differences between six cities according to the table of Abu l-Ḥasan al-Marrākušī[180] (d. in or after ca. 660/1260 or ca. 680/1280)are as follows:

		Longitudinal difference	Modern value
Tangier L 24°10'	— Antioch 69°34'	45°23'	42°00'
Tangier L 24°10'	— Rome L 43°00'	18°50'	18°20'
Toledo L 28°00'	— Alexandria L 63°00'	35°00'	36°00'
Toledo L 28°00'	— Constantinople L 60°00'	32°00'	33°00'
Alexandria L 63°00'	— Antioch 69°34'	06°45'	06°05'

The length of the Mediterranean between Tangier and Antioch, still at 45°23' in Abu l-Ḥasan al-Marrākušī, appears once more reduced and improved as 44°00'[181] with his younger colleague Muḥammad b. Ibrāhīm Ibn ar-Raqqām[182] (d. 715/1315). The resulting longitudinal differences are:

		Longitudinal difference	Modern value
Tangier 25°00'	— Antioch 69°04'	44°04'	42°00'
Tangier 25°00'	— Rome 45°00'	20°00'	18°20'
Toledo 28°00'	— Rome 45°00'	17°00'	16°32'
Toledo 28°00'	— Alexandria 61°20'	33°20'	33°55'
Alexandria 61°20'	— Antioch 69°04'	07°44'	06°05'

The substantial reduction of geographical longitudes carried-out in the Arab–Islamic world reached Europe relatively early on, at least through the table by Ibn ar-Raqqām. This is included in an anonymous Latin text entitled *Latitudo et longitudo regionum sicut continetur in Libro alg'alien*.[183] Even though this manuscript may well date from the 14th century, neither that nor any other coordinate table found any use in European cartography for centuries. Wilhelm Schickard and Willem Janszoon Blaeu were the first in Europe to point out—as late as 1630—the distorted representation of the Mediterranean on maps,[184] and it took until about 1700 before the length of the Mediterranean was established with tolerable accuracy.[185] But how far removed Europe was from an exact mathematical representation of the Mediterranean, even in the second half of the 17th century, is illustrated by an overview of the divergent values recorded for the difference in longitude between Rome and Toledo which Michael Florentius van Langeren presented to the [117] Spanish King

[180] v. F. Sezgin, op. cit. vol. 10, pp. 168–173.
[181] ibid, vol. 10, pp. 166, 231.
[182] ibid, vol. 10, p. 165.
[183] MS Vienna, Nationalbibliothek 2452, cf. F. Sezgin, op. cit. vol. 10, p. 231.
[184] F. Sezgin, op. cit. vol. 11, pp. 129,132.
[185] ibid, vol. 11, p. 132 ff.

Philipp IV (d. 1665): Blaeu had assigned it 17°20', G. Mercator 20°, Ph. van Lansberge 21°, Tycho Brahe 21°30', Cl. Ptolemy 22°40' (for which read 26°40') and A. Maginus 29°40'. In reality it is 16°32'.[186]

At this point the discussion of the depiction of the Mediterranean in Arab cartography as adopted in the West could be closed, if the unrealistic notions purported by historians of cartography were restricted to the origin of the so-called portolan charts of the Mediterranean. But such notions are also applied to a larger geographical area which is not believed to have been sailed by European mariners and the maps of which do not fall, strictly speaking, in the category of Mediterranean portolans. Thus one tacitly supports the common practice of not questioning the origins of maps of remote countries and entire continents such as Asia and Africa, or, should they be questioned, to assume they are original works by European cartographers who are supposed to have created them on the basis of information gathered by some sort of inquiries.

The map bearing the name of Giovanni da Carignano, who was the rector at the Marcus Church in Genoa and died in 1344, can serve as an interesting example. It is supposed to have been made around 1311[187] and comprises, besides the Mediterranean, the Black Sea, Europe and North Africa, Anatolia, Iraq and Persia with the Caspian Sea and Lake Urmia. This map, lost during World War II, was dealt with at length by Theobald Fischer in 1885.[188] According to his opinion, the considerable part of the surface of the Earth depicted here was rendered quite accurately by Carignano in Genoa solely on the basis "of questioning travellers" or by means of other "inquiries". Without repeating my criticism of his reasoning and motives,[189] I content myself here with the concluding remark that most of Fischer's finds regarding Carignano's map actually point to at least one map representing more or less the latest development of Arab–Islamic cartography in the second half of the 7th/13th century that served as a model for Carignano. It may be expected that the shapes of the Caspian Sea and Lake Urmia in this original already reflected a further development of cartographic depiction than the state we know e.g. from the Idrīsī map of 549/1154. Carignano might have used the Idrīsī map as well, but his main model must have been a more recent map from the Arab–Islamic world in which cities were included that have been named only since the 6th/12th century by the Anatolian Seljuks.[190]

A cartographic phenomenon to which in my view the historians of the subject did not pay adequate attention consists in the fact that one of the 'portolan' charts, viz. the one by Sanuto and Vesconte (infra III, 14), which dates from 1320 at the latest, already shows Africa with a circumnavigable shape, and that in another one from around 1351 the delineation of Africa shows signs of considerable improvement.[191] This attempt at correction becomes significant considering also the other parts of the cartographic work connected to it, known in modern literature as the Medici Atlas:[192] this atlas [118] also features a fairly realistic delineation of the Caspian Sea[193] and the triangular shape of the Indian peninsula,[194] besides some quite perfect regional maps of the Mediterranean and the Black Sea.

As far as I know, the Sinologist Walter Fuchs is the only scholar so far to have turned against the assumption that such a delineation of Africa

[186] P. J. H. Baudet, *Leven en Werken van Willem Jansz. Blaeu*, Utrecht 1871, p. 77; F. Sezgin, op. cit. vol. 11, p. 132.

[187] v. F. Sezgin, op. cit. vol. 12, p. 129.

[188] In his *Sammlung mittelalterlicher Welt- und Seekarten italienischen Ursprungs und aus italienischen Bibliotheken und Archiven,* Marburg 1885 (reprint: Amsterdam 1961 without maps), p. 118 ff.

[189] v. F. Sezgin, op. cit. vol. 10, pp. 332–335.

[190] ibid, vol. 10, p. 335.

[191] ibid, vol. 10, p. 549, vol. 12, p. 137.

[192] ibid, vol. 12, maps 71 a–h, pp. 136-140.

[193] ibid, vol. 10, p. 475.

[194] ibid, vol. 10, p. 568.

in a European map could be due to the original achievements of a European map–maker. He came to this conclusion through his study of the Chinese world map from the turn of the 14th century which had been drawn on the basis of an image of the world dating from the end of the 13th century that had reached the eastern Mongol empire from the Islamic world and astonishes us with a depiction of the Mediterranean quite close to reality and the delineation of the triangular shape of South Africa. Fuchs[195] emphasises that it is hard to believe that such a depiction could have been a coincidence. He would tend to assume that the cartographic heritage of the Arabs had only been incompletely handed down and that those cartographers did not always reflect the current level of experience of their seafarers.

Unfortunately, it happens not infrequently that new elements appearing on European maps of the 14th century—regardless of what name the map may bear—are traced back to clues in Marco Polo's travelogue, even if these are quite meagre or insignificant.[196] I assume it is unnecessary to argue against the naïve view that it was possible to draw a tolerably realistic map of any part of the surface of the Earth on the basis of Marco Polo's scattered, casual and often incorrect geographical information, or in fact of any observations made by travellers. The role played by Marco Polo or any other European Orient-traveller in the history of cartography can only have consisted in their bringing home cartographic material from foreign countries. Thus it is not surprising that Marco Polo, the Venetian businessman who visited on his outward journey the realm of the Ilkhāns (1272) and on his homeward journey (1294/1295) several cultural centres of the eastern Islamic world such as Tabrīz, where mathematical geography was cultivated in the 13th century, would encounter world maps and nautical charts of which he then saw to procure copies and sketches.[197]

In the early 1930s, one map became known while four others followed in subsequent years, which Marco Polo is said to have had in his possession during his journey to Asia.[198] They show roughly drawn coastal lines of South and East Asia, but also a remarkably accurate rendition of the Indian subcontinent and of the Malayan Archipelago. Of importance to us also are Arabic details and their Italian translations found on two maps surviving in a dilettante copy, one of which states that the map had been presented to Marco Polo in 1287 (erroneously 1267 in the manuscript) by a Syrian captain called Sirdumab (?), who sailed between Syria (Arabia) and the Far East for thirty years.[199] I believe that these sketches represent the rudimentary outlines of some Arab–Persian world maps and nautical charts known to Marco Polo, the likes of which, in more developed formats and with greater detail, repeatedly found their way [119] to European cartographers over the centuries.[200]

In the course of the reception and revision of models from the Arab–Islamic area, countless non-graduated world maps were produced in Europe during the 14th and 15th centuries. Surely, not all of these maps were copied from originals, but frequently copies of copies and not free from the particular map–maker's fancy. Only one of the most famous specimens shall be mentioned here, the map by Fra Mauro, a monk from the Camaldulensian (Benedictine) monastery on Murano off Venice, made between 1457 and 1459 upon the suggestion of the Portuguese

[195] *Was South Africa already known in the 13th century?* in: Imago Mundi (London) 10/1953/ 50–51; F. Sezgin, op. cit. vol. 10, pp. 323, 563.

[196] v. F. Sezgin, op. cit. vol. 10, pp. 318, 320, 337, 469, 484, 533, 556, 558, 563, 569, 570, vol. 11, pp. 102, 409, 414.

[197] ibid, vol. 10, pp. 315-316.

[198] ibid, vol. 10, p. 316.

[199] ibid, vol. 10, p. 317.

[200] ibid, op. cit. vol. 10, p. 318.

King Alfonso V (1433–1481).[201] In comparison the configurations of the map and its depiction of the three continents with the Mediterranean and the Black Sea turn out akin to the above-mentioned world maps by Brunetto Latini and Sanuto-Vesconte which in turn, as shown above, were based on Arab models. A new element compared to the two predecessors appears on Fra Mauro's map in the fairly accurate shape of the Caspian Sea. It is to be noted that its north–south axis is rotated counter-clockwise by about 70°. In all probability this rotation is a consequence of fixing-a regional map of the Caspian Sea into the world map forming the basis. It should also be mentioned that the map is southern-oriented as was the Arab custom and that more recent research pointed out the Arabic origin of the designation of the Atlantic in it: "Ocean of Darkness" (*al-Baḥr al-muẓlim*).[202] Moreover, it is stated in an inscription that an (Arab) vessel circumnavigated the South-African cape from the east and sailed into the Ocean of Darkness covering about 2000 miles in 40 days in unfavourable voyage.[203] R. Hennig[204] found that in this report "the most important fact from the point of cultural history is that Fra Mauro had no reservations referring to Africa as circumnavigable in the south, on the basis of those Arabic reports about sea voyages around 1420." Moreover, a view circulated in the 16th century to the effect that Fra Mauro had compiled his world map on the basis of a "beautiful and very old world map and nautical chart" which Marco Polo and his father had brought from China.[205] I understand that this would have been an Arab–Persian map acquired by the Polos in an Islamic country on their (supposed) return from China, whereby the actual model used by Fra Mauro does of course by no means necessarily stem from the Polos.

A certain degree of familiarity with the new image of the world created by Arab–Islamic geographers brought about an augmentation of knowledge in the field of mathematical geography in Europe, yet insecurity and confusion spread as well, caused by the edition of the Ptolemaic *Geography* in the Latin translation of around 1406, in print from 1477. The length of the Mediterranean—ca. 53° on the world map of the Maʾmūn geographers, the actual value being 42°—now appeared as 63° in the translated work of Ptolemy with its tables, and on the maps reconstructed according to those tables by the Byzantine Maximos Planudes around 1300 CE. The distance of India from the Canary Islands found on those maps was 125° (instead of 115° according to the Maʾmūn geography); Asia [120] was connected in the south-east to Africa, the Indian Ocean thus turning into a land-locked sea; the Asian continent stretched in the east and north-east beyond L 180°, the Caspian Sea spread about 23° from east to west in the shape of a melon, etc. Map–makers and cosmographers had the choice of whether they would stick to the version of the Maʾmūn geographers or would adopt that of Ptolemy. One of the key elements of the Arab-Islamic image of the world, namely that Africa is circumnavigable in the south and that the Indian Ocean is part of the ocean surrounding the oikoumene, did, however, prevail against the Ptolemaic view. A world-map [206] which appeared around 1483–1488, shortly after the first edition of the Latin translation of Ptolemy's *Geography,* is peculiar in combining the Arab–Islamic concept of an oikoumene surrounded by ocean with the Ptolemaic view of the Indian Ocean as a land-

[201] v. R. Hennig, *Terrae incognitae. Eine Zusammenstellung und kritische Bewertung der wichtigsten vorcolumbischen Entdeckungsreisen an Hand der darüber vorliegenden Originalberichte,* vol. 4, Leiden 1956, p. 55.

[202] v. R. Hennig, op. cit. vol. 4, p. 48.

[203] ibid, pp. 45, 49.

[204] ibid, p. 54.

[205] v. *The celebrations of the 700th anniversary of Marco Polo's birth at Venice*, in: Imago Mundi (London) 12/1955/139–140, esp. p. 139b; F. Sezgin, op. cit. vol. 10, pp. 318–319.

[206] v. F. Sezgin, op. cit. vol. 11, p. 86, vol. 12, p. 124.

locked sea. On the one hand it displays a rather good knowledge of Europe and a largely correct shape of the Caspian Sea, whilst on the other hand reflecting the Christian view that Paradise lies to the east of the oikoumene where the four main rivers of the Earth rise.[207]

This ambivalence noticeable in European world maps since the introduction of Ptolemy's *Geography* could, however, not remain decisive for the new development which had begun in Europe in the 13th century. In fact, the Ptolemaic image of the world could not hold its ground for long, or to be precise, no longer than half a century, against the one found on the maps which reached Europe from the Arab–Islamic area mainly through Portuguese expeditions. Already with the first voyage of Vasco da Gama an almost perfect representation of Africa and of the western part of the Indian Ocean with the Indian peninsula reached the Iberian peninsula and Italy. This was followed by further maps, particularly an atlas with 26 regional maps written in Javanese script; the representation of the Indian Ocean in this atlas, *inter alia*, testifies to the high level achieved in the cartographic survey of the Earth surface in the Arab–Islamic area before ca. 905/1500. The Portuguese seafarers in the Indian Ocean make no secret of having brought maps from there to Portugal and of having encountered advanced compasses and a highly sophisticated navigation amongst Arab seafarers. Moreover, Portuguese sources give detailed information to the effect that maps of the Indian Ocean with circumnavigable shapes of Africa got into Portuguese hands from the first half of the 15th century.This ultimately encouraged people in Portugal to head for India on the sea route which had long been known.[208]

Around 1550, at a time when the regress ion in the depiction of the world map that had begun in Europe with the translation of Ptolemy's *Geography* still prevailed, the maps brought by the Portuguese began to make their impact. From the viewpoint of the history of cartography one can hardly overemphasise the importance of what we hear in this connection from Gian Battista Ramusio (1485–1557), a Venetian with a special interest in geography and travel accounts:[209] "Since the representation of Africa and India on the maps in Ptolemy's *Geography* appeared very imperfect to me in view of the considerable knowledge about these regions which we nowadays have, I thought it expedient and not a little useful to collate the news from authors of our times who have travelled the parts of the Earth mentioned [**121**] and treated them in detail and to illustrate them with nautical charts of the Portuguese, so that other such maps can be produced to the utmost satisfaction." The maps reproduced by Ramusio comprise: 1) *Africa,* 2) *Arabia-Persia-India,* 3) the *Isole Moluche* (Southeast Asia) and 4) a regional map of Africa. Besides the fact that all maps are south-oriented as was the Arab custom, their toponomy as well as the scales of longitudes and latitudes leave no doubt as to their Arabic origin.[210] Yet, rather than the maps supplied by Ramusio himself, it was the map of Asia by a friend of Ramusio, Giacomo Gastaldi,[211] that perplexed contemporary cartographers and still astonishes historians of cartography today. It appeared in the years 1559–1561 under the influence of Ramusio's maps. How Gastaldi, an engineer from Venice, who had dedicated himself to the publication of Ptolemaic maps since 1539, suddenly came to prefer an entirely different representation of Asia remains an inexplicable phenomenon in the history of cartography to this day. His contemporary, the well-known cartographer Abraham Ortelius, who made his own version of Gastaldi's map with a few minor

[207] v. F. Sezgin, op. cit, vol. 11, p. 86.

[208] ibid. vol. 11, pp. 358–362.

[209] *Navigationi et viaggi*, vol. 1, Venice 1563 (reprint: Amsterdam 1970), dedicatoion, p. 2; F. Sezgin, op. cit. vol. 11, pp. 99–100.

[210] F. Sezgin, op. cit. vol. 11, pp. 100–103.

[211] ibid, vol. 12, map 113b–d pp. 177–179.

changes, remarks in the bottom right-hand corner of his map of Asia:[212] "[Herewith] we offer to the inclined reader a newer depiction of Asia which Jacobus Gastaldus, a man of great merit in the field of geography, [prepared] according to the tradition of the Arabian cosmographer Abu l-Fidāʾ. Guillaume Postel, the famous mathematician who was also proficient in many languages, including Arabic, has brought this author from the Middle East to our Europe…".

I see the significance of this remark with regard to the history of geography in the fact that Ortelius obviously thought the appearance of a map of Asia like Gastaldi's was possible only on the basis of the Arab tradition. Whether the coordinates in Abu l-Fidāʾ's book would have sufficed to design the configuration of a map or whether they were indeed congruent with Gastaldi's map of Asia he certainly did not question. Neither could any one of his predecessors, contemporaries or successors in Europe have known that the geographical coordinates filed by Abu l-Fidāʾ in a comparative table date from before the turn of the 13th to the 14th century and do not yet take into account the reduction of longitudes through the shift of the prime meridian to a position 28°30' west of Toledo. After all, even Ortelius did not know that Gastaldi had for his part used one or several Arab maps as models which already complied with the prime meridian 28°30' to the west of Toledo.[213]

The reaction of his contemporaries to the cartographic data provided by Gastaldi in his maps of Asia must have been tremendous; this can be recognised, *inter alia*, from the fact that three years after the maps had been given pride of place on the wall of the Senate hall in Venice, extensive tables were compiled of the identifiable places with their coordinates.[214]

The most striking difference between the older ("Ptolemaic") and the younger ("Arabic") depiction of the Earth surface as applied by Gastaldi consists, in my opinion, in the fact that in the latter, Asia is no longer spread all over the map right to the edges in the north and the east as part of one continuous land mass, but has been assigned an oval, circumnavigable shape. This representation of the north-eastern edge of Asia after Arabic models which had already appeared sporadically in earlier European [122] world maps, now gains general currency on contemporary and subsequent maps. This includes not only the circumnavigability of Asia in the north-east, but also its reduced size and its saddle-like shape, features not derived from the Maʾmūn map. In this respect the Idrīsī map proves to be the oldest surviving model. Without repeating my explanation here,[215] I may state that this important innovation dates back to the period before al-Idrīsī (549/1154) and continued to influence the development of the cartography of Asia in subsequent centuries.[216] In this connection we should also mention the dispute kindled around 1570 on the question whether Asia was circumnavigable in the north, which was denied by G. Mercator and A. Ortelius at that time.[217]

Ortelius's remarks in the bottom right-hand corner of his map of Asia and the question of the Arabian source of Gastaldi's maps of Asia were repeatedly discussed in the 20th century.[218] A convincing answer was not to be expected from the conventional opinion, that the portolan and world maps originated in Europe as long as the state of the cartographic–historic research did not permit consideration of an influence exerted by maps from the Arab–Islamic world. To make matters worse, there was almost no knowledge of the enormous development of mathematical geography in the Islamic world which could have provided the key to solving the entire com-

[212] F. Sezgin, op. cit. vol. 12, p. 182.
[213] ibid, vol. 11, pp. 99–116.
[214] ibid, vol. 11, p. 108.
[215] ibid, op. cit. vol. 11, p. 119.
[216] ibid, vol. 11, pp. 108-109.
[217] ibid, vol. 11, p. 80.
[218] ibid, vol. 11, pp. 104–107.

plex of the graticules on which European maps were based or with which they were supplied.[219]

The importance of the innovations which Gastaldi introduced into the European cartography of the old oikoumene cannot be overestimated. Its greatest effect seems to have been caused by the maps of Asia by Abraham Ortelius and Gerhard Mercator. Ortelius gave the map of Asia a globular projection with some reduction in topographical errors. The extension of Asia between the eastern edge of the Mediterranean and the southern tip of India given on Gastaldi's world map as ca. 47° or 48° was adopted almost unaltered by Ortelius for his globular projection. In Mercator the same section in stereographic projection is reduced to 44°.[220]

Historians of geography have found various different ad-hoc explanations for the corrections on the graticules of the world maps which appeared subsequent to Gastaldi's maps of Asia. Not wanting to repeat their views, I should rather like to give an account of the impression I gained during my study of mathematical geography and cartography in Islam and their continuation in the West.[221] The corrections made by 16th century European cartographers to fundamental dimensions of the world maps circulating in Ptolemy's name were neither undertaken on the basis of coordinates which had been taken from tables and appeared to be superior, nor on coordinates arrived at by original measurements. They were the result of adopting maps from the Arab-Islamic world which were seen as superior. To my present knowledge Kepler is the first to have endeavoured to produce a certain degree of congruence between the representation of the Mediterranean as found in current maps and the coordinates accessible to him on tables. The fruits of these endeavours which are known to us are a world map and a table of geographical places with [123] an explanatory introduction. Kepler had announced this map but did not live to produce it, hence it was drawn by his friend Ph. Eckebrecht, a citizen of Nuremberg, and published in 1630. The basic dimensions of the Old World such as the distances of the southern tip of India from the western edge of the Mediterranean, the longitude of the major axis of the Mediterranean and the distance between the east coast of Africa and the west coast of Sumatra at the Equator are similar, on this world map, to those on the maps of his predecessors Gastaldi, Ortelius and Mercator. His innovation to cartography lies in his treatment of the western basin of the Mediterranean.[222]

Kepler left behind quite a heterogeneous geographical table of places in which he tried to harmonise Ptolemaic coordinates with those stemming from the first reduction of the length of the Mediterranean by 10°, effected by Arabic geographers. As a result we see that in his table and his map the eastern basin of the Mediterranean is about 10° too large—in compliance with the Ptolemaic figures, whereas the length of the western basin with the reduction by 10° is in accordance with the most advanced maps from the Arab–Islamic area and almost reaches the actual values. Fortunately, this distorted representation of the Mediterranean did not find any notable dissemination.[223]

Subsequent to Gastaldi's maps of the years 1559–1561 there was no substantial progress made in the development of the fundamental dimensions and the cartographic shape of prominent parts of the Old World, with the exception of the northern parts of Europe, until about the middle of the 17th century. Variations are restricted to decorative features or the mechanical shifting backwards and forwards of the African west coast in the graticule of the maps.[224]

Only in the course of increased contacts of European scholars with the Islamic world, shortly

219 F. Sezgin, op. cit. vol. 11, p. 108.
220 ibid, vol. 11, p. 111.
221 ibid, vol. 11, p. 116.
222 ibid, vol. 11, pp. 121–122.
223 ibid, vol. 11, p. 124.
224 ibid, vol. 11, p. 117.

before the middle of the 17th century, did the European maps of Asia begin to attain a higher quality. Part of this consisted in the fact that it became more common to mention where the maps, brought from eastern countries or evaluated locally, had originated. In this respect the map of Persia brought back by Adam Olearius (1599–1671) figures, in my view, as a milestone. This scholar from Gottrop knew some Arabic and joined a trade delegation headed by Otto Brügmann travelling to Persia via Russia.

The journey lasted from 22nd October 1636 to 1st August 1639 and the description was published, together with the map, in 1647.[225] The reaction of his colleagues at the University of Leipzig to the map was that he deviated "from the Opinions hitherto current among all Geographers."[226] They would not understand "wherefore he be at Variance with the world-famous ancient Geographers Ptolemy, Strabo, Dionysius Alexandrinus and others in the Delineations of the Persian Map, and especially of the Caspian Sea."[227]

Olearius's account in his memories of the stay in Shamakhia (Š amāḫā), capital of Shirvan (Š arwān), is very instructive, not only regarding the origin of the map,[228] but also for the general history of cartography. There he had the opportunity to become friends with an Arab astronomer and a theologian. The astronomer, who hailed from the Hejaz and called himself [124] Ḫalīl (al-)Munağğim, placed at his disposal the table of longitudes and latitudes "of almost the whole of Asia and also several Sections of detailed Maps which had been drawn." Olearius adds that he had enclosed some of the maps in the edition of his book.[229] He also relates that in order to occupy him, the leader of the expedition, O. Brügmann, asked him to combine the two "maps of Persia and Turkey in one".[230]

The limits of the sectional maps of Persia and eastern Turkey, which Olearius combined, transliterating their text into Latin letters, extend in longitude (on the northern edge) from 62° to 108° and in latitudes from about 23° to 48°. The prime meridian of the graticule lies 28°30' west of Toledo. A comparison of the position of cities on the map with coordinates in the geographical tables which emerged subsequent to the foundation of the Maragha observatory in the sixties of the 7th/13th century, for instance with the table of Naṣīraddīn aṭ-Ṭūsī (d. 672/1274), shows that both longitudes and latitudes match.[231] Hence this map gives a good idea what an Arab-Islamic map from the period after the foundation of the Maragha observatory looked like and proves that they were graduated and very exact. Yet I believe that the map made accessible to the western world by Olearius represents a high, but not quite the highest stage reached in the cartographic depiction of this region in the Arab–Islamic world. It is however a great pity that this highly important document has so far not found adequate attention in the historiography of cartography.

The view of the Old World to which Europe was accustomed was supplied with new elements in the case of Asia by the French court cartographer and author of the first French world atlas, Nicolas Sanson d'Abbéville (1600–1667). If we disregard the map of Persia and eastern Anatolia introduced in Europe by Olearius, Sanson remains, to our knowledge the first European cartographer to express in all clarity that he took his map of Asia "from al-Idrīsī and other (Arab) authors" and that he had in part taken the

[225] *Vermehrte newe Beschreibung der Muscovitischen und Persischen Reyse*, Leipzig 1656 (reprint: The Islamic World in Foreign Travel Accounts, vol. 3–4, Frankfurt 1994).

[226] ibid, p. 204; F. Sezgin, op. cit. vol. 10, p. 398.

[227] Olearius, *Vermehrte newe Beschreibung*, op. cit. preface, p. 8a; F. Sezgin, op. cit. vol. 10, p. 398.

[228] F. Sezgin, op. cit. vol. 12, p. 211.

[229] Olearius, *Vermehrte newe Beschreibung*, op. cit. p. 434.

[230] ibid, p. 434; F. Sezgin, op. cit. vol. 10, p. 400.

[231] F. Sezgin, op. cit. vol. 10, pp. 402, 423–424.

representation of Tartary (Siberia) from maps which in turn had been produced on the basis of travel accounts and various Arab authors who had lived at that time. The map of Persia was a similar case.[232]

To a still greater extent and more clearly than his regional maps, the various editions of Sanson's maps of Asia and of the world yield an insight into how he kept improving his delineations on the basis of new models becoming available over the years. This impression is particularly striking when comparing his maps of Asia of 1650, 1651, 1654, 1659 and 1669.[233] The outstanding importance of the 1659 map consists, in my view, in the fact that it is the first European representation of Asia based on a graticule with the prime meridian at 28°30' west of Toledo and taking into account the radical improvements in longitudes achieved in the Arab–Islamic area.[234]

One of the new elements on this map of Asia in contrast to the previous one, drawn five years earlier, is the shape of the Red Sea with the Gulf of ʿAqaba which had long since disappeared from European maps. The melon-shaped form of the Caspian, on an east–west alignment, [125] which for more than a century one cartographer had copied from the other, gives way to an almost realistic representation of this same lake. Three Siberian and Central Asian lakes, which may represent Lake Baikal, Lake Balkhash and Issyk-kul, appear for the first time together on a European map. Furthermore there is a new type of representation of mountains and rivers.[235]

Not only geography-historical, but also toponymical and topographical considerations lead to the assumption that Sanson must have had an old map of Asia of Arab-Islamic origin as his model. Topographical and toponymical traces lead us to conclude that the original which Sanson used reflected a cartographic development in north-east Asia which may have taken place in the last half of the 5th/11th century. It is very likely that we are dealing here with Kīmāk Turks, who inhabited Siberia prior to the 6th/12th century. We find references to their work in al-Idrīsī's geography and maps.[236]

With all due respect for the innovations introduced by Sanson into European geography with his major cartographic representations, I do not believe he possessed a reliable criterion for evaluating the longitudes and latitudes which became available to him as court cartographer. He probably made his selection according to the good reputation or the place of origin of a map whereby he benefited from the intuition of an experienced geographer. After Sanson it took only two decades until a breakthrough in the history of European cartography occurred, by establishing a direct connection between maps and the measurement of longitudes. Like the preceding decisive steps in the evolution of mathematical geography, this too enjoyed dedicated official support. It came from Louis XIV in the context of the Academy which he had founded, to which an observatory was also added. On the initiative of Jean Dominique Cassini (d. 1712), the observatory's director, a new element for determining longitudes became effective in mathematical geography (supra p. 108).

In the first phase, an attempt was made "to correct the entire world map by proportionate reduction or modification of the larger land masses." Thus the astronomers created the *Planisphère terrestre*, a monumental world map on the floor of the west tower of the Paris Observatory. It was published in an improved reproduction by Cassini's son Jacques in 1694 or 1696 as *Planisphère terrestre suivant les nouvelles observations des astronomes.*[237]

A comparison of the coordinates of important localities of the Old World on this map and cor-

[232] F. Sezgin, op. cit. vol. 11, p. 117.
[233] ibid,vol. 12, pp. 167, 186,187, 188, 189.
[234] ibid, vol. 11, pp. 120–121.
[235] ibid, op. cit. vol. 11, p. 118.

[236] v. ibid, vol. 11, p. 118.
[237] v. ibid, vol. 11, p. 140, vol. 12, p. 168.

responding values in Arabic geographic tables with improved longitudes shows that, despite some deviations the Arab longitudes are more often correct than those of Cassini's world map.[238]

Then, towards the end of the 17th century, attempts were made in Paris to correct the world map with the aid of longitudes determined through observation of the Jupiter satellites by means of a telescope. It took a very long time to accomplish this task which has, perhaps, not even been completed yet today. Right from the initial phase of this project, but well into the 19th century and in individual cases even later, attempts at correcting the cartographic representation of the surface of the Earth by proportionate reduction of the longitudes of the inherited maps [126] have not yielded any satisfying results, at least not applied to the latest models created in the Arab–Islamic world. Extant examples show that their longitudes, reckoned from the respective prime meridian, turned out 2° to 3° too large. Yet when longitudinal differences are compared with those on modern maps, e.g. the between Aleppo and Samarqand or between Baghdad and Delhi, they prove to be either almost correct or with deviations in the region of a few minutes. The attempts at correction remained, moreover, limited for quite a long time to the positions of prominent localities in the interior of countries or on the coasts. It also turned out that coastlines and the outlines of countries which had been established locally by the work of generations in most cases remained valid well into the 20th century. In this connection, it is illuminating to hear what the Sicilian Arabist M. Amari[239] said around the middle of the 19th century about the state of affairs in the cartographic depiction of his home country. He had to realise that no map of Sicily existed in his day that "had been drawn on the basis of general triangulation" and that such a task requiring "merely time and money" had actually been started but then immediately abandoned again on several occasions.

For his attempt to draw an acceptable map of Sicily, Amari relied on the regional map of the island contained in al-Idrīsī's book, which had survived in a sole small-format copy, and on the configuration from the "least imprecise" map of his time into which he transferred the topographical features and the distances from al-Idrīsī's description.[240] He determined the degree of precision of the data provided by al-Idrīsī by comparing the sum of the distances recorded by the latter between the coastal points with the sum of the individual stretches of the coastline measured by the English captain W.H. Smyth between 1814 and 1824. When converted, this produced a largely concurrent result of 1050 km in al-Idrīsī as against 1041 km in Smyth.[241] It may be noted that the map of Sicily by Pīrī Reʾīs[242], which shows a more advanced depiction compared with Idrīsī, was still unknown to Amari.

After the advances made by the astronomers of the Paris Observatory in modifying, as far as possible, the world map which had been checked at several points by reducing it some degrees in its longitude or by moving parts of the Old World westwards, the young member of the Paris Academy, Guillaume Delisle (1675–1726) took on the task of continuing the work, the results of which are referred to in the history of cartography as the "reform of cartography". His achievement was however, like that of his predecessors and contemporaries, judged in complete ignorance of the vast preliminary work accomplished in the Arab–Islamic area. In the light of the Arab–Islamic maps and tables

[238] v. F. Sezgin, vol. 11, pp. 141–143.

[239] A.H. Dufour, M. Amari, *Carte comparée de la Sicile moderne avec la Sicile au XIIe siècle d'après Édrisi et d'autres géographes arabes. Notice par M. Amari*, Paris 1859, p. 20 (reprint in: Islamic Geography vol. 5, pp. 63–111, esp. p. 80); F. Sezgin, op. cit. vol. 11, p. 35.

[240] Regarding the map, v. F. Sezgin, op. cit. vol. 12, p. 26.

[241] ibid, vol. 11, p. 35.

[242] ibid, vol. 12, p. 88.

of coordinates known to me, I have pursued the question in how far Delisle must have been dependent on these maps. The case was limited to cartographic material of Persia, the Caspian Sea, the Caucasus, and the Aral Sea. Some of Delisle's maps of these areas are remarkably accurate. Thus his map of Persia from the year 1724 provides a suitable example of how great his own contribution to this excellent representation may have been. Anyone who looks at this map more closely and compares it with the maps by Gastaldi and his [127] successors or with the earlier Delisle maps will wonder how he was able to produce this map of Persia in the course of a few years. It impresses us with a topography expanded ten- to twentyfold, a more advanced hydrography, a much better representation of the Caspian Sea, the coastlines of the Persian Gulf and the Arabian Sea up to the borders in the north-west of the Indian subcontinent. Our astonishment grows when we see that the map of Persia fixes in its graticule the positions of about six hundred places, among them rather obscure places, villages, spas (*ḥammāms*), caravanserais, bridges, passes, fortresses etc., in such a way that their longitudes and latitudes—to the extent that these places still exist or have been included in a modern atlas—correspond, with minor deviations, to reality. Now the question arises as to how Delisle, from his Paris workshop, obtained the almost correct geographical positions of those hundreds of places and the coastal outlines on his map of Persia? It is not conceivable in any other way than that the map published in 1724 relied on a model reflecting the climax of a century-old cartography based on mathematical geography of the region in question. The maps of Persia emanating from the Islamic world which were made accessible in European languages by Giacomo Gastaldi (1559–61), Nicolas Sanson (1655) and Adam Olearius (1637) are not sufficient as the sole models of Delisle's map. Despite unmistakeable common ground with earlier maps, the latter has an incomparably richer content and a greatly expanded graticule.[243]

The best way to answer this question in my view is a comparison of the map's graticule with the corresponding longitudes and latitudes of about fifty places in Arab–Persian tables whose prime meridian runs 28°30' west of Toledo. The result of this comparison (which I presented in detail in my book a few years ago)[244] convinced me that Delisle must have transferred *en bloc* the graticule of a local Persian map and its contents into his French edition without any proportionate shortening of the longitudes, let alone a change in latitudes. Hence his map can be considered a French translation of an Arab–Persian original which apparently represented the ultimate stage in the development of the cartographic depiction of Persia and the Caspian Sea at that time. In all probability the original dated from the 16th century.

This conclusion also applies to his maps of the Black Sea,[245] of the Caspian Sea[246] and of the Caucasus,[247] for which I content myself with a reference to my above-mentioned book. However, in the case of the Black Sea map, I may add that Delisle himself incidentally pointed out[248] that he had based this map exactly on a hand-written map highly respected in Constantinople, which [Jean-Baptiste] Fabre had brought to Paris. An Ottoman-Turkish copy of the map which had reached Paris and was used by Delisle as the model for his map of the Black Sea has, by happy coincidence, actually survived.[249] The scales of longitudes and latitudes on this map prove that the delineation of the Black Sea had

[243] v. F. Sezgin, op. cit. vol. 11, pp. 149–150.

[244] ibid, vol. 10, pp. 413–423.

[245] ibid, vol. 10, pp. 433–468.

[246] ibid, vol. 10, pp. 468–508.

[247] ibid, vol. 10, pp. 424–433.

[248] G. Delisle, *Détermination géographique de la situation et de l'étendue des différentes parties de la terre,* in: Histoire de l'Académie Royale des Sciences, année 1720. Paris 1722, pp. 365–384, esp. p. 381; F. Sezgin, op. cit. vol. 10, p. 448.

[249] v. F. Sezgin, vol. 12, p. 234.

reached a high [128] degree of precision under the Ottomans, and it turns out that the exact measurements of that Sea in degrees which Delisle had emphasised on his map are identical to the surviving Ottoman copy.[250]

In the context of the endeavours to replace the outdated cartographic depictions of the Old World with more accurate maps emerging at the turn of the 17th to the 18th century, we may also mention the map of Persia by the Dutch Orientalist Adrian Reland (1676–1718). According to the words of his younger contemporary Chr. Gottlieb Jöcher[251] (1694–1758), Reland had "made known various Maps of Persia, Palestine etc." The title of his map of Persia,[252] known so far reads in translation:[253] "Delineation of the Persian Empire from the Writings of the Greatest Arab and Persian Geographers, undertaken by Adrian Reland." Thus, according to his own account, Reland's contribution must have been the Latin translation or transliteration—possibly with certain modifications—of a map that had become available to him in the original language. The map itself corroborates this assumption by being based on the graduation of the 13th – 16th century Arab–Persian school of cartographers, whose prime meridian ran 28°30' west of Toledo. However, compared to Delisle's map of Persia, this map represents an earlier stage in the evolution of the cartographic depiction of this area.[254]

In the group of cartographic depictions of parts of Asia which had thus become available in Europe and which had originated in the Arab–Islamic area, the map of Persia[255] by J. Baptist Homann (1663–1724) offers an interesting example of how maps of that period featuring a graticule were not in fact revised on the basis of coordinates gained by new astronomical concepts or methods, but that map–makers either copied maps at hand or compiled incongruous models dating from different periods. Homann, who was an extraordinarily productive cartographer, based his map of Persia, as he states himself, on works by Olearius, Tavernier, Reland, taking into consideration the work of recent authors.

Besides the toponymic, topographic and configurative peculiarities of this map,[256] we should mention the bizarre character of its graticule which is obviously caused by Homann using models with conflicting graticules. Two of his models, the maps by Olearius and Reland, had a graticule with the prime meridian at 28°30' west of Toledo, according to which the eastern shore of the Mediterranean is situated at a longitude of 70°, Baghdad at 80° and the west coast of the Caspian Sea at 85°. As we have repeatedly mentioned, this graticule shows a correction of longitudes by roughly 10°, compared to the world map of the Ma'mūn geographers from the first quarter of the 3rd/9th century, in which the eastern shore of the Mediterranean is found at L 60°, Baghdad at 70° and the western shore of the Caspian Sea at 75°. By comparison it becomes obvious that the distances between those prominent points are identical in the Ma'mūn and in the Homann maps. This becomes even more striking when we consider Homann's map of the world[257], where the east–west axis of the Mediterranean has a length of about 54°, i.e. it is almost [129] identical with that in the Ma'mūn geographers at about 53°.[258] From this follows that Homann neither knew that the longitude of the Mediterranean had been reduced to 44° in the Arab–Islamic world, nor the correction to

[250] F. Sezgin, op. cit. vol. 10, pp 448–449.

[251] *Allgemeines Gelehrten-Lexicon*, Dritter Theil, Leipzig 1751 (reprint Hildesheim 1961), column 2002–2004.

[252] F. Sezgin, op. cit. vol. 12, p. 214.

[253] In the original: *Imperii persici delineatio ex scriptis potissimum geographicis arabum et persarum tentata ab Adriano Relando*, cf. F. Sezgin, op. cit. vol. 10, p. 407.

[254] F. Sezgin, op. cit. vol. 10, p. 407.

[255] ibid, vol. 12, p. 216.

[256] ibid, vol. 10, pp. 407 ff.

[257] ibid, vol. 12, p. 205.

[258] ibid, vol. 10, p. 410-411.

42° that since 1700 had been achieved by the French astronomers.

The longitudinal differences between cities in Persia as they appear in Homann's map betray a connection with the world map of the Ma'mūn geographers as well. Contrary to my earlier assumption that Homann used the map by Olearius as his model for the map of Persia, I am increasingly induced to believe that the main model of Homann's map must have been the map of Persia made available in Europe by the French scholar Jean-Baptiste Tavernier (1605–1689), who had travelled Turkey, Persia and India for about 40 years. The coordinates of 130 places which are registered in Tavernier's *Les six voyages en Turquie, en Perse et aux Indes*[259] show that he knew only the Ma'mūnian and post-Ma'mūnian coordinates reckoned from the Canary Islands and that the longitudes corrected by later Arab–Islamic scholars remained unknown to him.[260]

Homann's map of Persia—which, compared with those of Olearius and Reland, was generally speaking a regression, with only the Caspian Sea being giving a conspicuously improved shape, probably through the mediation of Tavernier; yet Homann's map must have acquired great fame very quickly, with the result that it was translated into Turkish within a few years and printed in İstanbul in this version in the year 1141/1729.[261] My impression is that it forms the basis for the map enclosed in the *Ǧihānnumā* by Ḥāǧǧī Ḫalīfa (1732) on the regions of Transoxania.[262] Some western geographers and cartographers like Emmanuel Bowen (after 1738)[263] and James Rennell (1793)[264] actually took it for an original Ottoman-Turkish map.

It is one of the mysteries of the history of geography that, after the Ottomans had made great progress since the 15th century in the cartographic representation and mathematical survey of the regions under their rule, in 1732 an Ottoman map–maker adopted his map of the eastern shore of the Caspian Sea with Transoxania and the adjacent territories, apparently without any qualms, from the atlas of a European cartographer, without having the slightest inkling of how closely those cartographic representations followed models which had been developed in the Islamic world in the course of the previous centuries. The Ottomans were obviously dazzled by the progress made by the Europeans in the art of cartography, their descriptions of the newly discovered areas of the Earth, and their intensive study of the cartographic heritage. They were not in a position to assess where weaknesses lay in the maps produced by the Europeans in the previous centuries, being unable to see that the Europeans' knowledge of Central, Northern and North-East Asia was still extremely patchy, [130] and that as in the past they were obliged to fall back on the achievements of the Arab–Islamic civilisation.[265]

Two maps of northern Asia from the Arab–Islamic world reached Europe at approximately the same time as Homann's map of Persia and were disseminated in French translation. One might call them the oldest maps of Siberia, but they actually cover Asia beyond Siberia to 25° in the south, and they contain the oldest virtually correct representations of the Black Sea, the Caspian Sea, the Aral Sea and the Transoxanian river system known to us. As part of the book

[259] Paris 1679, vol. 1, p. 390.

[260] v. F. Sezgin, op. cit. vol. 10, p. 409.

[261] ibid, vol. 12, p. 217.

[262] ibid, vol. 10, pp. 411–412, vol. 12, p. 104.

[263] From the inscription on the left hand margin of his *Map of Turky, Little Tartary, and the Countries between the Euxine and Caspian Seas* (cf. F. Sezgin, op. cit. vol. 12, p. 225), we learn that, in his editing of the depicted areas, he used, inter alia, a map of Persia printed in Istanbul in 1729 (v. ibid, vol. 10, pp. 455–456).

[264] In his *Memoir of a map of Hindoostan or the Mogul Empire*, Second part, London 1793 (reprint: Islamic Geography vol. 261), p. 225, he writes in connection with a river in Guǧarāt (Gujerat): "I found the same name in a map of Persia *drawn and engraved* at Constantinople, in the year 1729" (see F. Sezgin, op. cit. vol. 10, p. 618).

[265] F. Sezgin, op. cit. vol. 10, p. 412.

on the genealogy of the Turks by Abu l-Ġāzī Bahādur Ḫān (b. 1012/1603, d. 1074/1663),[266] both maps found their way from Turkestan to Tobolsk. There the book came to the notice of Philipp Johann Strahlenberg (b. 1676), a Swedish officer who was taken prisoner by the Russians in 1710 and deported to Siberia in 1711. He saw the book with a "Tatarian-Mahometan priest", a cleric of the Siberian Tatars by the name of Agun Asbackewitz (Āḫund Özbekoġlu?), who had been given it by emissaries from Turkestan and "preserved among their documents".[267] Together with another prisoner known as Peter Schönström and with the assistance of the Tartar cleric, Strahlenberg saw to it that the book was translated, via Russian into German. The fame of the book must have spread so fast and so far in European geographical circles that the German translation was published in an anonymous French translation as early as in 1726, together with the maps prepared in a German version by Strahlenberg in 1715 and 1718.[268] After his release from captivity, back home in Sweden, Strahlenberg published a foreword (*Vorbericht*) to the translation of the book by Abu l-Ġāzī (1726), a book of his own entitled *Das Nord- und Oestliche Theil von Europa und Asia* (1730) and a map of Asia (1730). His comments on this German edition of the map are partly unclear, partly misleading, so that knowledge of the true state of affairs escapes the reader, giving the impression that Strahlenberg was talking of a map which he himself compiled during the first four or seven years (between 1711 and 1715 or 1718) of his captivity in Tobolsk.[269]

The older one of the two maps is designated as the depiction of North Asia at the time of the Mongol invasion and in French translation bears the title: *Carte de l'Asie Septentrionale Dans l'Estat où Elle s'est trouvée du temps de la grande Invasion des Tartares dans l'Asie Meridionale sous la Conduite de Zingis-Chan pour servir à l'Histoire Genéalogique des Tatares.*[270] The title of the more recent map is as follows: *Carte Nouvelle de l'Asie Septentrionale dressée Sur des Observations Authentiques et Toutes Nouvelles.*[271] Both maps are graduated and, predominantly by this feature, allow us to verify their Arab–Islamic origin and to obtain definite clues for their date of origin by comparing their graticules with geographical tables of cities. The comparison of coordinates provides us with irrefutable evidence that we are dealing with two of the most significant cartographic documents of the Arab–Islamic world. The results allow us to date the older map to the 7th/13th or the 8th/14th century [131] and the more recent one to the second half of the 10th/16th century. With their coastlines, river systems and further topographic and toponymic elements besides their graticules, they corroborate our established view that the early development of the cartographic representation of North and Central Asia as reflected, relative to the Ma'mūn geography, in the world and regional maps by al-Idrīsī (549/1154), continued beyond this stage. In this later phase of development, we find that the positions of lakes and rivers flowing into the Arctic Ocean, which were placed somewhat roughly on Idrīsī's map, are now drawn in accordance with their true coordinates in our two maps. The representations of the two Asiatic land-locked seas, the Caspian and the Black Sea, have gained a remarkable precision compared with their configuration in al-Idrīsī's world map. Those two important water basins, in their longitudes and latitudes and in their position relative to each other, now reach almost accurate dimensions in the graticule. They provide us with fur-

[266] French translation *Histoire généalogique des Tatares*, 2 vols. Leiden 1726; text with French translation by Baron Desmaisons, *Histoire des Mogols et des Tatares*, 2 vols. Petersburg 1871, 1874 (reprint: Islamic Geography, vol. 225–226).

[267] F. Sezgin, op. cit. vol. 10, p. 379.

[268] ibid, vol. 10, p. 378.

[269] ibid, vol. 10, p. 380.

[270] ibid, vol. 12, p. 173.

[271] ibid, vol. 12, p. 201.

ther clues for tracing the Arab–Islamic basis of the graticules which have appeared in European maps since Ortelius and Mercator.[272] Of these two maps, with which I have dealt at length in the context of the cartography of Asia,[273] the older one, as a work of the 13th–14th centuries CE, completely agrees with the familiar development in the cartographic representation of the Mediterranean, of Africa with its insular shape, of South Asia and of the Indian Ocean and thus fills an essential gap, while the more recent one with all its progressive features emerges as an extremely important document of Arab–Islamic cartography from the second half of the 16th century CE.

I conclude these observations on the two maps of North and Central Asia with a remark on the cartographic representation of the Caspian region in the first half of the 18th century, penned by the great Russian Arabist W. Barthold (1869–1930),[274] to whom we owe significant achievements in the field of the history of Arabic geography. Barthold describes the role of the Arab–Islamic area in the history of geography with deep respect and appreciation and continues: "Individual Arab maps were already being used by Europeans in the Middle Ages; some works by Arab geographers appeared in Latin translation as early as in the XVIIth century; despite this the detailed and accurate information of the Arabs on the Caspian and Aral Sea, the Oxus and Jaxartes had no influence on European science. What Western Europe could have learnt 800 years earlier from the Arabs was only learnt from the Russians in the XVIIIth century. The correction of earlier ideas about the Oxus, the Jaxartes and the Caspian Sea is among the earliest findings of Russian research to be accepted by Western European science. In Remezov's map of 1697, the Aral Sea (More Aralsko) is depicted for the first time as a landlocked sea completely separate from the Caspian, with the Aral Sea fed by the 'Amun-Darya' (Amu Darya, Oxus), the 'Syrt' (Syr Darya, Jaxartes) and several small rivers. More detailed information on the geographical [132] situation in the area in question was collected in Russia at the beginning of the XVIIIth century and passed on to the French court geographer Delisle by Peter the Great, partly in person (during his stay in Paris in 1717), partly by letter. On Delisle's 1723 map the Aral Sea is mentioned for the first time using this name, although the Greek Basilios Batatzes claimed that he had been the first to bring news of this inland sea to Europe in 1732, causing a sensation in London. At any rate, the maps of the XVIIIth century prove that people still had a very hazy notion of the geographical position of the area concerned and sought to rescue as much as possible from the Greek geographers' assertions; Delisle even marks a river from the Aral Sea to the northern part of the Caspian as the 'ancien cours de la rivière Sir'."

In two points of this thoughtful exposition, in particular, I have arrived at more differentiated views than Barthold, thanks to the more favourable situation today. The first point is that I am convinced that it was the maps of Arab geography rather than their descriptive passages which much more profoundly influenced the European map–makers, thereby ushering in a new epoch, and this influence was not restricted to work on the Caspian and the Aral Sea. The second point is that what had previously been regarded, in connection with the cartography of the Caspian or the Aral Sea; as the fruits of the research activity of Russian scholars in the first quarter of the 18th century can today be proven to be the rediscovery of the achievements of Arab–Islamic

[272] F. Sezgin, op. cit. vol. 10, p. 396.

[273] ibid, vol. 10, pp. 376-396.

[274] *Nachrichten über den Aral-See und den unteren Lauf des Amu-darja von den ältesten Zeiten bis zum XVII. Jahrhundert. Deutsche Ausgabe mit Berichtigungen und Ergänzungen vom Verfasser. Nach dem russischen Original übersetzt* von H. von Voth, Leipzig 1910, v. preface pp. VI–VII (reprint: Islamic Geography vol. 100, pp. 245–336, esp. pp. 248–249); F. Sezgin, op. cit. vol. 10, pp. 344–345.

geographers by the European, and among them, Russian cartographers of the 17th century.

As regards the first point, it should be noted that, in the case of the Caspian Sea especially, the transmission of eastern influences to the West suffers from discontinuity and a lack of uniformity. Maps of Islamic origin deriving from different periods and representing different stages of development found their way to European cartographers. The latter, however, who were supposed to base their own maps on the models accessible to them, had no means of assessing their degree of accuracy. Thus the earlier, more accurate representation of the Caspian Sea seems to have been gradually consigned to oblivion from the early 16th century, i.e. after the dissemination of the printed version of Ptolemy's *Geography* with its unrealistic depiction of the Caspian.[275]

The various maps brought to Europe in the 17th and 18th centuries by travelling scholars like Jean Chardin, Melchisédec Thévenot, Jean-Baptiste Tavernier, François Petis de la Croix senior and junior, François Bernier, Jean-Baptiste Fabre, William Kirkpatrick or James Rennell cannot be discussed individually here; hence I shall restrict myself to two examples that seem suitable for illustrating the attempts of European cartographers to make the best possible use of map material and coordinate tables which had become accessible to them.

The first example refers to the caption, mentioned above, on the *Map of Turky, Little Tartary, and the Countries between the Euxine and Caspian Seas*[276] by the English cartographer Emmanuel Bowen (after 1738). In it Bowen states that for his map assembled from various models, he made use, apart from the map of eastern Anatolia and Persia which had appeared in 1729 in İstanbul, of the following map materials, inter alia: the representation of the coast of the Black Sea from the Azov Straits up to the northern mouth of the Danube was taken from a Turkish map… the River Tigris and parts around Basra follow an Arab map[277] [133] which was appended to Thévenot's collection of travelogues.[278] In the case of the lakes Van and Urmia (*Shahi*), he states that he did not follow G. Delisle, whose map of Georgia he had used, in representing them as almost contiguous since the latter had "produced no authority for such a considerable alteration." Bowen goes on to name a few more maps by European contemporaries to which he had recourse. In a second inscription he lists coordinates. They are latitudes for a number of places which he cites as the results of observations of older and younger contemporaries, or gleaned from Arabic tables like those of Ibn Yūnis, al-Battānī or Naṣīraddīn aṭ-Ṭūsī. He omits the longitudes of the Arabic tables, except for one by al-Battānī. He probably did that because he could not cope with the different prime meridians of the Arabic tables.[279]

The second example is about the well-known French geographer and cartographer Jean-Baptiste Bourguignon d'Anville (1697–1782) and how he dealt with an Ottoman-Turkish map of the Red Sea probably made between 945/1538 and 948/1541. According to his description, this map[280] depicted the Red Sea from the north down to Jeddah (Ǧudda), and he used it in drawing the northern parts of the map *Golfe Arabique ou Mer Rouge* appended to his *Mémoires sur l'Egypte ancienne et moderne.*[281] Noteworthy here is d'Anville's hint that he had taken the representation of the Gulf of as-Suwais (Suez) and

275 F. Sezgin, op. cit. vol. 10, p. 345.

276 ibid, vol. 10, p. 455, vol. 12, p. 225.

277 ibid, vol. 12, p. 226.

278 It is *Relation de divers voyages curieux, qui n'ont point esté publiés et qu'on a traduits ou tirés des originaux des voyageurs français, espagnols, allemands, portugais, anglais, hollandais, persans, arabes et d'autres Orientaux, le tout enrichi de figures et de cartes géographiques*, Paris 1663–1667.

279 F. Sezgin, op. cit. vol. 10, pp. 455–457.

280 ibid, vol. 12, p. 317, northern part.

281 Paris 1766 (reprint, Islamic Geography, vol. 256) to p. 276.

the Gulf of ʿAqaba from this Turkish map. He says that he owes to it, inter alia, the knowledge of a spit of land (which actually does not exist) projecting southwards into the Gulf of ʿAqaba, splitting, as it were, the northern end of the gulf into "two gulfs of their own". This means that d'Anville had, in the second half of the 18th century, still no means of judging from Paris to what extent the representation of the Gulfs of Suez and ʿAqaba and the Sinai Peninsula were drawn correctly in this Ottoman map.[282] Hence it should not surprise us that it took no less than half a century to correct this error in European cartography.[283]

D'Anville and the Englishman James Rennell (1742–1830, supra p. 111 ff.), the two most illustrious geographers and cartographers of the 18th century, showed great respect and due appreciation for the achievements of their Arab–Islamic predecessors. Not only did they rely in their descriptive accounts regarding the maps of Asia and Africa to be revised with confidence on descriptions, geographical coordinates and other data concerning distances of their Arab–Islamic sources, they also consulted maps which had originated in the Arab–Islamic world and which they had become aware of in the course of their work. To quote sources and name models was not an established tradition, least of all in cartography. In this connection it is instructive that as late as 1755 the cartographer Robert de Vaugondy[284] reproved an omission of this sort made earlier by his colleague d'Anville: "As far as the Asian [134] part of Turkey and the Persian Empire are concerned, we would like to know the originals which provide the basis of the new information supplied by M. d'Anville in the first part of his [map of] Asia: they contain details different from what can be expected from the accounts of a traveller. The topography which they represent can only have been taken from hand-drawn regional maps, after local measurements, and the knowledge of which would doubtless be very useful for us."

[282] F. Sezgin, op. cit. vol. 11, pp. 417–419.
[283] ibid, vol. 11, p. 419.
[284] *Essai sur l'histoire de la géographie ou sur son origine, ses progrès et son état actuel*, Paris 1755, p. 385; F. Sezgin, op. cit. vol. 10, p. 457.

Routes of Arab–Islamic Sciences into Europe

The preceding part of this introduction dealt with the process of reception and assimilation of Arabic-Islamic sciences in the West, in particular in the fields of philosophy, astronomy, music, medicine and geography, starting from some existing studies on this matter which have the character of preliminary works or which seek to explain the process on the basis of certain literary documents, rather than the subjects. Here now the routes on which the process of reception and assimilation in the West begann shall be discussed briefly.

1. The route via Muslim Spain

Surely the oldest and best known route is the one originating on the Iberian peninsula, which came under Arab rule almost completely within 20 years of the invasion of 711. The sciences pursued by the conquerors during the next one and a half centuries there were largely the same as those cultivated in the centre of the Islamic world.

At an earlier stage of the acquaintance with the subject was reached the view that the first encounter of the Christian West with Arab–Islamic science occurred in the last third of the 10th century through personal contacts between individuals from both areas in the Hispanic Marches around Barcelona. In this process, Gerbert of Aurillac (b. ca. 950, d. 1003), elected Pope Sylvester II in 999, was considered a forerunner.

In the case of the introduction of Arabic numerals into the Christian West which had been

connected with his name,[285] new documents and references have meanwhile emerged that are not related to him. Thus Arabic numerals appear in two manuscripts, copied in the Hisppanic Marches in 976 and 992 CE respectively. These important documents preserved in the library of the Escorial have not yet been considered by the historians of mathematics.[286] Moreover, in an extant letter by Gerbert we discover that he asked the abbot Gerald of Aurillac to obtain for him the treatise *De multiplicatione et divisione numerorum* by one Joseph Sapiens (or Hispanus),[287] from which it becomes evident that the knowledge of Arabic numerals must have found its way to the south of France even before this time.[288]

Moreover, an astrolabe from the 10th century is extant (infra II, 91), the Latin inscription of which turns out to be a transliteration [135] of what were originally Arabic letters. Marcel Destombes, who discovered the astrolabe and owned it at the time, identified it as "Carolingian" on account of the type of script used and recognised an early acquaintance with Arabic numerals outside Arab Spain in the numbers on the back and on the disc[289] which are expressed by the letters of the Latin alphabet. The quite perfect form of the astrolabe which, according to a note dates from 980, presupposes a certain amount of familiarity with the application and construction of the instrument, at least regarding a limited geographical area. Another surviving astrolabe (infra II, 94) is attributed to Gerbert himself, but is most probably not his work.

The extant treatises *De mensura astrolabii* or *De utilitatibus astrolabii* and a *Geometria* bear Gerbert's name. Their authenticity and their dependence on Arabic sources have not yet been explained in detail and with certainty. An in-depth study by Arabic studies is still due. In 1888 H. Weissenborn came to the conclusion that "the methods and instruments of measurement as described in the second part of the so-called Gerbert geometry originated with the Arabs."[290] In his study of geodetic instruments (1912), J. Würschmidt[291] came to the additional result "that the majority of the problems dealt with in Gerbert's geometry were solved by contemporary Arab scholars in mostly the same form and with the same devices; the latter discussed a number of other, more complicated problems, while the Gerbert geometry only compiled those problems which can be solved with the most basic methods and in the shortest time."

The astrolabe treatise betrays its Arabic origin quite clearly. It was however not a direct Latin translation of an Arabic original, but seems to have been based indirectly on another Latin text which presumably for its part was a translation of an Arabic work on the astrolabe. Even

[285] v. H. Weissenborn, *Gerbert. Beiträge zur Kenntnis der Mathematik des Mittelalters*, Berlin 1888; idem, *Zur Geschichte der Einführung der jetzigen Ziffern in Europa nach Gerbert*, Berlin 1892.

[286] v. A. van de Vyver, *Les premières traductions latines (X^e^ – XI^e^ s.) de traités arabes sur l'astrolabe*, in: 1^er^ Congrès International de Géographie Historique. Tome II. Mémoires, Paris and Brussels 1931, pp. 266–290, esp. p. 286 (reprint in: Islamic Mathematics and Astronomy, vol. 90, pp. 377–405, esp. p. 400).

[287] N. Bubnov, *Gerberti opera mathematica*, Berlin 1899 (reprint: Hildesheim 1963), p. 101.

[288] A. van de Vyver, *Les premières traductions*, op. cit. pp. 286, 288 (reprint, pp. 400, 403).

[289] Marcel Destombes, *Un astrolabe carolingien et l'origine de nos chiffres arabes*, in: Archivs internationales d'histoire des sciences (Paris) 15/1962/3–45, esp. pp. 42–43 (reprint in: Islamic Mathematics and Astronomy, vol. 96, pp. 401–447, esp. pp. 444–445); Paul Kunitzsch and Elly Dekker, *The stars on the Rete of the so-called "Carolingian Astrolabe"*, in: *From Baghdad to Barcelona.* Studies in the Islamic Exact Sciences in Honour of Prof. Juan Vernet, Barcelona 1996, vol. 2, pp. 655–672.

[290] *Gerbert. Beiträge zur Kenntnis der Mathematik des Mittelalters*, op. cit. p. 168; J. Würschmitdt, *Geodätische Messinstrumente und Messmethoden bei Gerbert und bei den Arabern*, in: Archiv für Mathematik und Physik (Greifswald) 3rd series 20/1912/315–320, esp. p. 316 (reprint in: Islamic Mathematics and Astronomy, vol. 87, pp. 357–362, esp. p. 358).

[291] *Geodätische Messinstrumente,* op. cit. p. 320 (reprint, op. cit. p. 362).

though its table of the seven climata with the corresponding place names is an element alien to Arabic astrolabe treatises, the very contents of this table—which cannot be explained without the knowledge of an Arabic source[292]—indeed reveal a connection with the world map of the Maʾmūn geographers. However, we cannot judge whether the author of the Latin astrolabe treatise inserted the table himself, or whether the translator found it already included in the Arabic original and took it along with the text. Either way, this is but one of several clues to the Maʾmūn geography and its book of coordinates having reached the Iberian peninsula quite early on.

The early date of the Latin treatise on the astrolabe attributed to Gerbert can be explained more easily in the light of [136] a work on the astrolabe also written in Barcelona which was supposedly penned by a contemporary of Gerbert by the name of Lupitus, probably also a cleric. It is assumed that a copy of the little book by Lupitus was at the disposal of Gerbert or the author of the treatise which bears his name.[293]

J. M. Millas Vallicrosa, who edited the treatise by Lupitus entitled *Sententie astrolabii* on the basis of six manuscript copies,[294] still believed it was a direct Latin translation of an Arabic original. The true nature of this astrolabe treatise was revealed only fifteen years ago by Paul Kunitzsch in an article entitled *al-Khwārizmī as a Source for the Sententie astrolabii.*[295] Kunitzsch compared the Latin monograph with the Arabic treatise on the astrolabe by Muḥammad b. Mūsā al-Ḫwārizmī[296] (active under the Caliph al-Maʾmūn, r. 198/813–218/833). The comparison showed that of the three parts of the *Sententie*—a short introduction, a description of the astrolabe and a section on its use—the first part was apparently freely formulated by the Latin compiler, the second, by its terminology betrays a strong Arabic influence and the third section is one seventh a literal translation from al-Ḫwārizmī's text and the rest made up of long explanations and comments by the Latin editor.[297] Whether Lupitus dealt with his Arabic model in this way because he had problems with the literal translation, or because he wanted to be seen as an independent author of the booklet we cannot know. At any rate he did not conceal the Arabic origin of his knowledge, as he left many technical terms and names of stars which he adopted untranslated. Moreover, he inscribed the Arabic alphanumeric characters not in transcription but in Arabic script on the discs and on the back of the mater. Yet he did not mention the name of al-Ḫwārizmī, the author of his source.

This treatise which imparts the content of al-Ḫwārizmī's treatise in a dishonest way exerted a profound influence on the astrolabe literature in Europe from the beginning of the 11th century to the 16th century,[298] even though it was not the only treatise of its kind that made the contents of Arabic works on this subject available in Latin works. To all appearances Gerbert's treatise was the first to draw on Arabic models. The question of whether Gerbert himself wrote it or one of his pupils or followers did is still open. How great the influence of the *Sententie astrolabii* was can be seen, above all, in the fact that an extensive body of anonymous Latin writing emerged as

[292] v. Uta Lindgren, *Ptolémée chez Gerbert d'Aurillac,* in: *Gerberto. Scienza, storia e mito.* Atti del Gerberti Symposium (25–27 luglio 1983), Bobbio (Piacenza) 1985, pp. 619–638.

[293] v. Harriet Pratt Lattin, *Lupitus Barchinonensis*, in: Speculum. Journal of Mediaeval Studies (Cambridge, Mass.) 7/1932/58–64, esp. p. 62.

[294] *Assaig d'història de les idees físiques i matemàtiques a la Catalunya medieval*, vol. 1, Barcelona 1931 (=Estudis Universitaris Catalans, Serie monogràfica vol. 1), pp. 275–293.

[295] in: *From Deferent to Equant:* A volume of studies in the history of science in the ancient and medieval Near East in honor of E.S. Kennedy, New York 1987, pp. 227–236.

[296] v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 5, pp. 228–241, vol. 6, pp. 140–143, esp. p. 143.

[297] P. Kunitzsch, *al-Khwārizmī,* op. cit. pp. 231–232

[298] ibid, p. 233.

an offshoot of this book and is preserved into our time.[299] The way to further adaptations and imitations outside Spain, in the North had thus already been paved in the first part of the 11th century.

The earliest known phenomenon in the imitative sense is a text entitled *De mensura astrolabii*. It bears the name of Hermannus Contractus, alias Hermann of Reichenau [300] [137] (1013–1054). Remarkable about this treatise is, inter alia, that its table of the seven climata and its listing the names of cities in an east–west order betrays a knowledge of the handbook of al-Farġānī even before it was translated into Latin.[301] Hermannus is also supposed to have been the one who introduced the portable cylinder clock and the quadrant from Arabic Spain into Europe.

Even if the possibility cannot be ruled out that the authorship of Lupitus and Gerbert for the works mentioned above is spurious or very doubtful, they are still important documents of the early period of reception of Islamic sciences by the Latin world via the Iberian Peninsula, after the social and economic contacts between Arabic Spain and the adjacent countries had already begun in the early 8th century. A. van de Vyver[302] gave an apt description of this process in 1931: "Ces adaptations latines de la fin du Xe siècle et du début du XI^{e}, – anonymes, brèves et mal composée, – font l'effet de notes et de traités de première initiation, qu'au cours du XI^{e} siècle on s'attacha à polir et à présenter sous une forme plus convenable. On pourra constater aussi, que ces premiers emprunts se sont effectués dans le domaine pratique, et concernaient notamment l'usage de l'astrolabe, du quadrant, de la sphère armillaire, des chiffres arabes, des recettes de médecine, des formules astrologiques, et moins vraisemblablement de l'abaque et, à cette époque, du calcul. La vitalité du Haut Moyen-Age était encore trop faible pour pouvoir s'assimiler les grands traités scientifiques des Arabes ou leurs systèmes philosophiques."[303] An important indication of the science-historical significance of this incompetent and dishonest manner in which the Arab–Islamic sciences were appropriated in the mediaeval Christian West, and the resulting interest in the knowledge to be borrowed from Arab Spain, can be seen in the fact that bishop Fulbert of Chartres[304] (ca. 975–1029) compiled a glossary[305] of 28 Arabic terms from available texts on the astrolabe.

The impact of the first wave of translations and imitations of Arabic works issuing from the re-conquered parts of Spain seems to have been limited at first to the immediately neighbouring region. The big translation-vogue only began at the turn of the 12th century. In the 11th century, after the work of Hermannus Contractus (d. 1054), we only encounter Walcher of Malvern towards the end of the century. He hailed from the Lorraine region to which Arabic astronomy and mathematics had found their way as early as in the 11th century; he was perhaps the first

[299] J. Millás Vallicrosa, *Assaig d'història…*, op. cit. p. 288 ff; P. Kunitzsch, *al-Khwārizmī,* op. cit. p. 233.

[300] Max Manitius, *Geschichte der lateinischen Literatur des Mittelalters*, vol. 2, Munich 1923, pp. 756–777; Claudia Kren, *Hermann the Lame*, in: Dictionary of Scientific Biography, vol. 6, New York 1972, pp. 301–303; Arno Borst, *Wie kam die arabische Sternkunde ins Kloster Reichenau?* Konstanz 1988; idem, *Astrolab und Klosterreform an der Jahrtausendwende*, Heidelberg 1989.

[301] v. F. Sezgin, op. cit. vol. 10, pp. 206–207.

[302] *Les premières traductions*, op. cit. p. 289 (reprint, p. 404).

[303] van de Vyver refers here to his essay *Les étapes du développement philosophique du Haut Moyen-Age*, in: Revue Belge de Philologie et d'Histoire (Brussels) 8/1929/425-452.

[304] v. M. Manitius, *Geschichte der lateinischen Literatur des Mittelalters*, op. cit. vol. 2, pp. 682–694.

[305] Edited by M. McVaugh and F. Behrends, *Fulbert of Chartres' notes on Arabic astronomy,* in: Manuscripta (St. Louis, Mo.) 15/1971/172–177; cf. P. Kunitzsch, *Glossar der arabischen Fachausdrücke in der mittelalterlichen europäischen Astrolabliteratur*, Göttingen 1983, pp. 481–482; idem, *Das Arabische als Vermittler und Anreger europäischer Wissenschaftssprache*, in: Berichte zur Wissenschaftsgeschichte (Weinheim) 17/1994/145–152, esp. p. 151.

European to have attempted successfully to determine the time-line of a lunar eclipse [138], which he accomplished in 1092 by observation with an astrolabe.[306]

The grand scale introduction of Arabic medicine by Constantinus Africanus in the second half of the 11th century shall be left aside here in this treatment of the west European part in the process of reception; it was mentioned already (supra p. 91 ff.) and shall once more be considered below in the context of the second route of reception and assimilation of Arab–Islamic sciences in the West.

After a possible first encounter in the early 9th century with sciences cultivated in the Islamic world, and their reception from the second half of the 10th century, the further development of which in the 11th century we can as yet not trace in detail, the first half of the 12th century brought about a great tide of translations from the Arabic into Latin and Hebrew. One of the leading pioneers of this movement was Adelard of Bath (active 1116–1142, supra p. 98). He, Robert Grosseteste (d. 1253) and Roger Bacon (d. 1292) may be regarded as the three foremost English scholars of the period of reception and assimilation. After long sojourns in Laon, Tours, Salerno and perhaps Syracuse as well as Tarsus and Antioch, he returned to England in 1120. With numerous translations and his own works he introduced, above all, a new astronomy and mathematics into Europe. With the translation of the *Zīǧ*[307] of the above mentioned Muḥammad b. Mūsā al-Ḫwārizmī in the revision by Abu l-Qāsim Maslama b. Aḥmad al-Maǧrīṭī (d. 398/1007), he acquainted his contemporaries with a handbook of Arabic astronomy which had already developed distinctive traits both in theoretical and in applied branches, on the basis of assimilated Indian and Greek works on the subject. The trigonometry and the trigonometric tables transmitted by the book, prepared the grounds for a future expansion of mathematical, astronomical and geodetic knowledge in Europe. Raymond Mercier[308] may be right in his comment that the Latin world was still not at all ready for such a work, resulting in the very slow pace of the process of assimilation, yet we should consider how long it would have taken the Europeans to create the knowledge of mathematics and astronomy, which they had acquired through translations from the Arabic, on their own.

Two further contributions of pivotal importance for mathematics and astronomy made by Adelard of Bath are the translations of the same al-Ḫwārizmī's Arithmetic and of Euclid's *Elements* from the Arabic.

The big stream of translations which the history of science knows from the 12th century was fed predominantly from Toledo. This city, conquered in 92/711 by the Arabs, had developed in the course of time into a scientific centre of high order and, with its scholarly tradition of collaboration between Muslims, Christians and Jews and with its great libraries, [139] came under Castilian rule in 478/1085. The scientific activities that developed after the fall of the city were described by Valentin Rose[309] in 1874 as "nursery (Pflanzstätte) of the 'doctrina Arabum'" for all Europe.

As early as in the first half of the 12th century, the first and decisive phase of the reception activities in Toledo, amazingly extensive

[306] v. Ch. H. Haskins, *Studies in the History of Mediaeval Science*, op. cit. pp. 114–117; H. Schipperges, *Die Assimilation der arabischen Medizin*, op. cit. pp. 149–150; P. Kunitzsch, *Glossar der arabischen Fachausdrücke*… op. cit. p. 483; F. Sezgin, op. cit. vol. 10, pp. 214–215; see also Raymond Mercier, *Astronomical tables in the twelfth century,* in: *Adelard of Bath. An English scientist and Arabist of the early twelfth century*, ed. Charles Burnett, London 1987, pp. 87–118, esp. pp. 102–103.

[307] v. F. Sezgin, op. cit. vol. 6, p. 142.

[308] *Astronomical tables in the twelfth century*, op. cit. p. 87.

[309] *Ptolemaeus und die Schule von Toledo,* in: Hermes (Wiesbaden) 8/1874/327–349, esp. p. 327 (reprint in: Islamic Mathematics and Astronomy, vol. 63, pp. 171–193, esp. p. 171).

translations were accomplished which would have been inconceivable without a preceding tradition—dating back to the Islamic rule—of cooperation between individuals of all three creeds. In this connection we may recall that in the 12th century, several generations after the reconquest of Toledo, the language there was still predominantly Arabic, albeit a vernacular, not literary Arabic (infra p. 143 under Gerard of Cremona).[310] The Mozarabs in turn "had maintained their churches, their Romanic dialect, their Visigothic traditions under their Muslim conquerors until the middle of the 12th century and, above all, also for a long time, their civic and legal rights… Thus they remained a people of their own, although in some respects they knew how to assimilate, in particular also in terms of language."[311]

The list of works translated by Johannes Hispalensis can give us an idea of the extent of the achievements of those times. This Jewish apostate, who converted to Christianity, translated about twenty works from the fields of arithmetic, astronomy, astrology, medicine and philosophy from Arabic into Latin,[312] including the Handbook of Astronomy by al-Farġānī (1st half 3rd/9th c.). Thus, after al-Ḫwārizmī's book, there was a second astronomical work available which—thanks to repeated translations—was to stay very popular with Western astronomers until well into the 17th century. Johannes Hispalensis was also the first to make at least seven Arabic works of philosophy available in Latin translation, including writings by al-Kindī, al-Fārābī and al-Ġazzālī.

Robert of Chester (Robertus Castrensis, Retinensis etc),[313] an Englishman who had lived in Spain from around 1141 to 1147, in collaboration with his compatriot Hermannus Dalmata, made the first Latin translation of the Koran. His great achievements also include the translation of the algebra book of the repeatedly mentioned Muḥammad b. Mūsā al-Ḫwārizmī[314] from the early 3rd/9th century, through which he became the first to introduce the term algebra and the mathematical processes connected with it into the Christian West.[315] The use of the word *sinus* ("bosom") being a literal translation of the misread Arabic term *ǧaib* (instead of *ǧīb* [140] for Sanskrit *jiva*) goes back to him as well.[316] Robert of Chester was also the first to translate works on alchemy from the Arabic into English.[317]

One of the most important works rendered into Latin in Christian Spain at this time is the Handbook of Astronomy by Muḥammad b. Ǧābir b. Sinān al-Battānī (d. 317/929).[318] Through this work, which was translated by Plato of Tivoli (who lived in Barcelona from 1134–1145) and again by Robert of Chester, whose version is not extant, in addition to the already mentioned works by al-Ḫwārizmī and al-Farġānī, the Latin world encountered a number of processes and concepts from the field of astronomy which had meanwhile been developed in the Islamic world.

[310] Arnald Steiger, *Zur Sprache der Mozaraber*, in: *Sache, Ort und Wort*, Festschrift für Jakob Jud, Geneva 1942 (Romanica Helvetica vol. 20), pp. 624–723, esp. p. 627; Heinrich Schipperges, *Assimilations-Zentren arabischer Wissenschaft im 12. Jahrhundert*, in: Centaurus (Copenhagen) 4/1955–56/325–350, esp. 336.

[311] H. Schipperges, *Assimilations-Zentren*… op. cit. p. 336, Angel Gonzáles Palencia, *Los Mozárabes de Toledo en los siglos XII y XIII. Volumen preliminar*, Madrid 1930, p. 117 ff.

[312] M. Steinschneider, *Die europäischen Übersetzungen aus dem Arabischen bis Mitte des 17. Jahrhunderts,* Vienna 1904 (reprint: Graz 1956), pp. 40–50; G. Sarton, *Introduction to the history of science,* vol. 2, part 1, pp. 169–172.

[313] v. Ch. H. Haskins, *Studies*… op. cit. pp. 120–123; G. Sarton, *Introduction* …op. cit. vol. 2, part 1, pp. 175–177.

[314] v. F. Sezgin, op. cit. vol. 5, p. 240.

[315] v. Ch. H. Haskins, *Studies*… op. cit. p. 122.

[316] v. G. Sarton, *Introduction*… op. cit. vol. 2, part 1, p. 176.

[317] ibid, p. 176.

[318] v. F. Sezgin, op. cit. vol. 6, pp. 182–187.

After this short survey of works translated from the Arabic into Latin in the first half of the 12th century, we shall also mention several scholars of the time who contributed to the assimilation of Arab science not only with translations but by then also with their own compilations. An interesting exponent of this group was Hermannus Dalmata or Hermann of Carinthia who, with Robert of Chester, translated the Koran. He lived from 1138 to 1142 in Spain and 1143 in Toulouse. Besides the translations of astrological books and of the notes[319] on Ptolemy's Planisphaerium by the above-mentioned Abu l-Qāsim Maslama b. Aḥmad al-Maǧrīṭī (d. 398/1007), we know several books that are ascribed to him[320] and one work of his own with the title *De essentiis*, which he dedicated to Robert of Chester. This philosophical work, written in 1143, is a conglomerate of text passages from Arabic and Latin sources.[321]

As a compiler along a similar line we encounter Raymond of Marseilles in his *Liber cursuum planetarum* composed from 1139 to 1140. With this book on astronomy and the geographical table contained therein—which stem from Arabic sources—he intended to render a service to his compatriots. Besides al-Battānī, he relied on the Toledan Tables and the Canon (*al-Qānūn*) of az-Zarqālī, whom he wanted to emulate. His geographical table contains the coordinates of 60 cities. Thus he was one of the first, if not indeed the first, Latin writer to make an Arabic coordinate table widely known in Europe.[322] His book was still to be found amongst the sources of Roger Bacon and was probably also used by Albertus Magnus (supra p. 103).[323]

The Jewish scholar Abraham bar Ḥiyya alias Savasorda (from Arabic *ṣāḥib aš-šurṭa*, "prefect of the watch"), who lived in the first half of the 12th century in Barcelona, should be mentioned here. His influence was not directly exerted through Latin translations, but his Hebrew writings in which he transmitted the contents of a large number of Arabic sources in his own words. According to George Sarton, he was one of the initiators of the movement in which Jews from the Provence [141], Spain, and Italy became mediators of Islamic science in the Christian West.[324] A complaint of his, namely that Arabic sciences were little known in the Provence, is known.[325] In his book *Ḥibbur ha-mešiḥa ve-hatišboret* he presents the basic elements of Arab algebra, geometry and trigonometry at a high level. Through the Latin translation of this book by Plato of Tivoli (1145), entitled *Liber embadorum,* he exerted a not insignificant influence on the development of mathematical knowledge in Europe, even if the aspects of Arab mathematics he covered had reached the West through different channels before him.[326] He probably also played some role in the transmission of Arab music theory into the West.[327]

319 F. Sezgin, op. cit. vol. 5, p. 170; Paul Kunitzsch and Richard Lorch, *Maslama's notes on Ptolemy's* Planisphaerium *and related texts*, Munich 1994.

320 v. Ch. H. Haskins, *Studies*...op. cit. pp. 43–66; G. Sarton, *Introduction*... op. cit. vol. 2, part 1, pp. 173–174.

321 H. Schipperges, *Die Assimilation der arabischen Medizin*, op. cit. pp. 124–125; Ch. S. F. Burnett, *A group of Arabic-Latin translators working in Northern Spain in the mid-12th century*, in: Journal of the Royal Asiatic Society (London) 1977–1978, pp. 62–108; *Hermann of Carinthia, De essentiis* A critical edition with translation and commentary by Ch. Burnett, Leiden 1982.

322 v. F. Sezgin, op. cit. vol. 10, pp. 210–211.

323 v. P. Duhem, *Le système du monde,* op. cit. vol. 3, p. 216.

324 G. Sarton, *Introduction...,* op. cit. vol. 2, part 1, p. 206.

325 v. Juan Vernet, *Die spanisch-arabische Kultur in Orient und Okzident,* Zurich and Munich 1984, p. 197.

326 G. Sarton, *Introduction*..., op. cit. vol. 2, part 1, p. 207; Martin Levey, *Abraham bar Ḥiyya ha-Nasi*, in: Dictionary of Scientific Biography vol. 1, New York 1970, pp. 22–23.

327 v. H.G. Farmer, *Clues for the Arabian influence on European musical theory,* in: Journal of the Royal Asiatic Society (London) 1925, pp. 61–80, esp. p. 71 (reprint in: H.G. Farmer, *Studies in Oriental music*, vol. 1, Frankfurt 1986, pp. 271–290, esp. p. 281); idem, *The Jewish debt to Arabic writers on music*, in: Islamic Culture (Hydera-

Amongst the subsequent translators whose activities lay mostly between 1150 and 1200, we may consider Dominicus Gundissalinus as the first exponent of assimilation. He stands out not as much as a translator but with books he compiled from his translations. In the case of the treatise *De celo et mundo* which he, in collaboration with Johannes Hispalensis, brought into circulation as a work by Ibn Sīnā and that was accepted as such for centuries, it was proven by Manuel Alonso[328] that the true author was Ḥunain b. Isḥāq[329] (d. 260/873). Gundissalinus' best known and most important book *De divisione philosophiæ* is also, in large parts, copied from *Iḥṣā' al-ʿulūm* by Abū Naṣr al-Fārābī[330] (d. 339/950). He seems to have used Latin models (e.g. Boëthius) and works by Ibn Sīnā and al-Ġazzālī as well, but he does not mention them as sources. In a commendable study Ludwig Baur[331] investigated the sources of Gundissalinus' *De divisione philosophiæ*. He discovered that it was suspected to be a work by al-Fārābī quite early on. "Considering the generous use of Al-Farabi's work (de scientiis) by Gundissalinus it is hardly a surprise hat this suspicion could arise."[332] Baur called the book a "free compilation."[333] "Gundissalin's compilatory method of working, as alien and inappropriate it may seem to us, must not surprise us: it was standard throughout later Antiquity and the Middle Ages… This kind of literary activity should, I believe, be seen in closest connection with the whole philosophical conception of knowledge and the pedagogic vocation, which separates Antiquity and the Middle Ages from modern times." About the mind set of the Middle Ages he says: "There we have a philosophy which believes in the possibility of definite, [142] objective, and permanent cognition of truth. All scientific interest was concentrated on truth as such, aiming for the discovery of truths to be firmly established once and forever. Those truths were public domain, and it was quite irrelevant who found them."[334] This explanation may be generally correct for the Latin authors and to some extent also for the ancient Greeks, the Arab–Islamic world, however, must be excluded from it. Unfortunately, too little attention has as yet been paid in the historiography of sciences to the fact that references to the sources was one of the characteristic traits of Arab–Islamic literature, which of course does not mean to say that there was no plagiarism or that all authors observed this general rule.

The manner in which Gundissalinus treated his sources and in particular the works of his Arab predecessors which he used in translations and perhaps also in the original, is characteristic of all works that bear his name.[335] Baur[336] also discovered that besides Gundissalinus' *De divisione philosophiæ*—which is "based upon a number of Arabic authors"—there was "a second [book] which was probably written in the beginning of the XIIIth century and which

bad) 15/1941/59–63, esp. p. 60 (reprint ibid, vol. 1, pp. 535–539, esp. p. 536).

[328] *Ḥunain traducido al latín por Ibn Dāwūd y Domingo Gundisalvo,* in: Al-Andalus (Madrid and Granada) 16/1951/37–47; H. Schipperges, *Die Assimilation der arabischen Medizin*, op. cit. p. 65.

[329] F. Sezgin, op. cit. vol. 3, pp. 247–256.

[330] ibid, vol. 3, pp. 298–300.

[331] *Dominicus Gundissalinus, De divisione phi-losophiae,* Münster 1903 (Beiträge zur Geschichte der Philosophie des Mittelalters, vol. 4, part 2–3).

[332] ibid, p. 160.

[333] ibid, p. 161.

[334] L. Baur, *Dominicus Gundissalinus*, op. cit. p. 315 ff.

[335] v. also Georg Bülow, *Des Dominicus Gundissalinus Schrift von der Unsterblichkeit der Seele,* in: Beiträge zur Geschichte der Philosophie des Mittelalters (Münster) vol. 2.3, 1897, pp. 1–38; idem, *Des Dominicus Gundissalinus Schrift von dem Hervorgange der Welt (De processione mundi),* ibid, vol. 24.3, 1925 pp. 1–54; *The treatise* De anima *of Dominicus Gundissalinus*, ed. J. T. Muckle with an introduction by Etienne Gilson, in: Mediaeval Studies (London) 2/1940/23–103; G. Sarton, *Introduction…,* op. cit. vol. 2, part 1, pp. 172–173; Claudia Kren, *Gundissalinus*, in: Dictionary of Scientific Biography, vol. 5, New York 1972, pp. 591–593.

[336] *Dominicus Gundissalinus, De divisione philo-sophiæ*, op. cit. pp. 364, 365.

likewise must have been completely Arabic in character: The *Divisio philosophiae* by Michael Scotus." Surviving fragments of this book show that it was a compilation using the work of Gundissalinus and Arabic sources.
This way of dealing with Arabic sources and their contents is a science-historic phenomenon which we encounter not only with Gundissalinus in the history of the reception and assimilation of the Arab–Islamic sciences in the West. We of present times must understand this as a typical practice of that civilisation at the time and we must take it into account accordingly. Hence historiography is called on to revise—assisted by Arabist research—the prevailing notions about the history of European science, particularly regarding the period between the 11th and the 13th century, in the light of the actual facts.

In the 12th century the process of translating Arabic and adapted Greek works from Arabic into Latin and Hebrew (which had already begun in the 10th century) reached its apogee, at a time when the sciences in the Arab–Islamic world were progressing creatively in almost all areas. The important development connected with the name of Gerard of Cremona is a phenomenon in the history of science that will perhaps remain for a long time without a well-founded explanation. Born around 1114 in Cremona, Italy, he moved to Toledo where he was active until his death in 1187. We know almost nothing about the life of this undoubtedly greatest translator of Arab–Islamic writings into Latin. Probably he was a cleric, like most translators of those days. A list of his translations compiled soon after his death[337] contains seventy-one [143] titles arranged by subjects: twenty of them deal with *dialetica* (logic and geometry), twelve with *astrologia* (mainly astronomy), eleven with *phylosophyia* and twenty-eight with *fisica* (medicine and others). To what extent this anonymous list—which is appended to some manuscripts of the Latin translation of the commentary by ʿAlī b. Riḍwān (d. 453/1061) on Galen's τέχνη ἰατρική[338]—conforms with reality is of course uncertain. Moreover, as G. Sarton already pointed out, further translations kept being ascribed to Gerard of Cremona later on, either erroneously or because of his fame. Sarton also drew attention to the fact that many of the first printed editions of translations attributed to Gerard of Cremona do not bear his name. Hence the ascriptions should not be taken too literally. For an Italian who went to Toledo as an adult and only there learned Arabic, the task of translating scientific works on all kinds of subjects from Arabic to Latin was certainly not easy. One should also bear in mind that Muslim scholars had left Toledo after the reconquest in 1085 and the only people left who spoke Arabic were the Christian Arabs (Mozarabs). Whether they could have been of much help with philological and terminological difficulties is however rather doubtful. In an article on Gerard of Cremona's translations, Paul Kunitzsch[339] gives an apt description of the linguistic situation in the reconquered Toledo: "What was the standard of knowledge of the Arabic language on the side of the translators? Regarding Gerard specifically, we know that he came to Spain from Italy, that means that he could not have had any knowledge of Arabic in advance. He will have learnt the language in Toledo. But what sort of Arabic is it that he could have learnt there? The

337 Edited by Baldassarre Boncompagni, *Della vita e delle opere di Gherardo Cremonese, traduttore del secolo duodecimo…*, in: Atti dell' Accademia Pontifica de' Nuovi Lincei (Rome) 4/1850–1851 (1852)/387–493, esp. pp. 388–391 (reprint in: Islamic Mathematics and Astronomy, vol. 79, pp. 9–115, esp. pp. 10–13); V. Rose, *Ptolemæus und die Schule von Toledo*, op. cit. p. 334 (reprint, op. cit. p. 178); K. Sudhoff, *Die kurze "Vita" und das Verzeichnis der Arbeiten Gerhards von Cremona*, in: Archiv für Geschichte der Medizin (Leipzig) 8/1914–15/73–82.

338 See F. Sezgin, op. cit. vol. 3, p. 81.

339 *Gerard's translations of astronomical texts, especially the Almagest*, in: Gerardo da Cremona, ed. P. Pizzamiglio, Cremona 1992 (Annali della Biblioteca Statale e Libreria Civica di Cremona vol. 41, 1990), pp. 71–84, esp. pp. 73–74

areas dominated by the Arabic language are known for their 'diglossia', that is that there existed—and still exists today—two languages side by side: the spoken colloquial Arabic generally used in oral speech, and the language of writing which is strictly dominated by the rules of the *fuṣḥā*, the classical literary Arabic."

In connection with the question of people from Toledo helping out with language skills, Daniel of Morley (last third of the 12th century), who spent some time in Toledo, is often quoted. In his *Philosophia,* he writes that Gerardus Toletanus was assisted in the translation of the *Almagest* by a Mozarab named Galippus (Ġālib).[340]

The difficult task of establishing, by a stylistic and terminological analysis, the true relationship of the seventy-one titles (mentioned on the list) to Gerard of Cremona has yet to be fulfilled. Leaving aside the fact that the list was compiled after his death, the manuscripts of the translations attributed to him as a rule do not include [144] a colophon by him and, with a few exceptions, do not name him as the translator. At any rate, it is very unlikely that all the translations on the list are actually his.[341] The number of works enumerated appears too large for a single translator and the vast range of subjects covered makes it difficult to believe that a man who had moved (from Cremona) to Toledo in his thirties, albeit a scholar of exceptional ability, should have been able to translate so many works into Latin. It is conspicuous that the list contains the names of some important works which had already been translated by others, such as the Arabic version of the *Elements* by Euclid, the *Algebra* by Muḥammad b. Mūsā al-Ḫwārizmī, or the handbook of astronomy by al-Farġānī. Nevertheless, we may assume that some of the works on the list are really original translations by Gerard of Cremona. Some extensive and extremely important works like Ptolemy's *Almagest*, *al-Qānūn fi ṭ-ṭibb* by Ibn Sīnā and the section on surgery of *at-Taṣrīf li-man ʿağiza ʿan at-taṣnīf* by az-Zahrāwī are amongst them, besides books by Hippocrates and Galen. The *Almagest* was, incidentally, rendered directly from Greek into Latin by an anonymous translator in Sicily around 1150, roughly 25 years before the Arabic translation by Gerard of Cremona was completed. According to one scholar[342] the translator may have been Hermann of Carinthia (Hermannus Dalmata). But whoever it was, the translation from the Greek did not gain any prominence in Europe. P. Kunitzsch[343] came to the general conclusion that works of Arabic origin enjoyed greater authority than others in the European Middle Ages prior to the rise of anti-Arabism.

Leaving aside the question of the real translators, the fact still remains that this list of translations attributed to Gerard of Cremona contains no less than seventy-one works that were supposedly translated from Arabic in Toledo. Further works rendered by other translators into Latin must be added. All these works together provide us with a glimpse of the process of reception of Arab–Islamic sciences in the 12th century. Its importance for the upsurge of sciences in Europe has not yet found a truthful expression in the general history of thought.

[340] See V. Rose, *Ptolemæus und die Schule von Toledo*, op. cit. pp. 335–336, 348 (reprint op. cit. pp. 179–180, 192); Ch. H. Haskins, Studies in the History of Medieval Science, op. cit. pp. 15, 126–127; Paul Kunitzsch, *Der Almagest. Die Syntaxis Mathematica des Claudius Ptolemäus in arabisch-lateinischer Überlieferung*, Wiesbaden 1974, pp. 85–86.

[341] v. P. Kunitzsch, *Gerard's translations of astronomical texts*, op. cit. p. 71

[342] See R. Lemay, *Hermann de Carinthie, auteur de la traduction "sicilienne" de l'Almageste à partir du grec (ca. 1150 A.D.),* in: *La diffusione delle scienze islamiche nel medio evo europeo. Convegno internazionale* (Roma, 2–4 ottobre 1984), Rome 1987, pp. 428–484.

[343] *Gerard's translations of astronomical texts*, op. cit. p. 73.

2. The Route of reception via Sicily and South Italy

When we follow Heinrich Schipperges' delineation[344] of the development in the field of medicine—according to which the reception started "in the cultural centres in southern Italy" and "after an extraordinary journey through Spain, France and England," returned "again to its original civilisation" where the first wave of reception had emerged from "the school of Salerno" in which Constantinus Africanus (ca. 1015–1087) had played the leading role—the question still remains open as to whether the medical practice and literature, which had been intensively cultivated in northern Africa from the 9th century onwards, could not perhaps have already spread to Sicily under Islamic rule, and from there to the Italian main land. After all, this large, central island in the Mediterranean [145] reached a high cultural and social standard under the Arabs from the 9th century to 1086 CE.[345]

The fall of Arab rule over Sicily did not immediately cause the new spirit and the new culture of the preceding two and a half centuries to wane. Under the third of the Norman kings, Roger II (r. 1130–1154), the Arabs still constituted a large part of the population.[346] "Roger employed many Arab civil servants and thus enabled the re-organisation of Arab institutions. The land registers, the defetari [*daftar* = booklet, register], which had been taken over from the Muslim administration continued to be kept in Arabic."[347]

"Like the organisation of the financial administration, the royal silk workshops too revived an Arab institution called *ṭirāz*. The mantle of Roger II, which served the German kings as a coronation robe, was made in the Norman palace workshop."[348]

"The palaces and parks Roger owned in and around Palermo were influenced by Arab taste and were built partly on the remains of Arab buildings and gardens. They were Sung by Sicilian-Arab poets whose verses combine the praise of Roger with that of his parks and palaces."[349]

The technology of the Islamic world and the sciences cultivated there were a major inspiration for Roger II, even if we hear little about it today and know not enough. As an example we may mention the clepsydra that was constructed for him in Palermo in 1142. A white slab of marble 87 cm long and 49 cm wide still remains of it today. It is no longer in its original place but built into the wall at the entrance to the Cappella Palatina in Palermo. An inscription[350] in Arabic, Greek and Latin provides testimony to Roger's work. Following E. Wiedemann's[351] rendition, the Arabic text runs in English: "The Royal Majesty, revered and exalted, Roger, whose days God may prolong and whose colours He may support, had this instrument (*âla*) constructed in order to observe the hours in the capital of Sicily guarded [by God] in the year 536 [AH]." As a clue to the question of what this clepsydra built for Roger may have been like, Michele Amari, the eminent expert on Arab Sicily, pointed to a report in a contemporary Arabic source, to the effect that an (Arab) engineer had built a water driven clock for the ruler of Malta with the figu-

[344] *Die Assimilation der arabischen Medizin*, op. cit. p. 185.

[345] On the literature, see the article *Ṣiḳilliya* in Encyclopaedia of Islam. New Edition, vol. 9, Leiden 1997, pp. 582–591, also Dietlind Schack, *Die Araber im Reich Rogers II.*, PhD. thesis. Berlin 1969.

[346] D. Schack, op. cit. p. 195.

[347] ibid, p. 195.

[348] ibid, p. 195.

[349] ibid, p. 196.

[350] Published repeatedly; on the Arabic text, see M. Amari, *Le epigrafi arabiche di Sicilia*, part 1, Palermo 1875, p. 39.

[351] *Auszüge aus arabischen Enzyklopädien und Anderes* (Beiträge zur Geschichte der Naturwissenschaften. V) in: Sitzungsberichte der Physikalisch–medizinischen Sozietät (Erlangen) 37/1905/392–455, esp. pp. 412–413 (reprint in: Wiedemann, *Aufsätze* vol. 1, Hildesheim 1970, pp. 109–172, esp. pp. 129–130).

rine of a girl tossing a ball into a metal bowl to announce the hours.[352]

The oldest Latin translation of an Arabic book known to have originated in Sicily was probably made upon the commission of Roger II. [146] It was Ptolemy's *Optics* translated by an admiral (or amīr, amiratus regis Siciliæ) by the name Eugenios.[353] The reason why no earlier translations from Sicily are known is certainly that prior to its re-conquest, the majority of the population of the island knew Arabic.

With regard to the reception and also the promotion of Arabic science, Roger deserves much credit since, thanks to his commission, with his support and to a certain extent even his personal participation, a geographical work and a world map were produced. It is the geography by aš-Šarīf al-Idrīsī entitled *Nuzhat al-muštāq fi ḫtirāq al-āfāq* and his world map which was engraved on a large silver plate (supra p. 37 ff). It is one of the oddities of the history of science that the book as such did not stir any noteworthy interest in Europe up to the 17th century. The world map, however, already seems to have exerted a profound influence on European cartography soon after it was made and continuing until the 18th century.

These first sporadic impulses emerging in Sicily from Arabic works in the original or in Latin translation can be regarded as signs of a period of incubation in the reception and assimilation of the culture and the knowledge of the neighbouring civilisation. The latter had been known for a long time, but from the end of the 11th century a completely new relationship was established. As far as we can judge from today, it is one of the most significant coincidences in the history of science that three important centres of science and culture in the Arab–Islamic world, with all their cultural assets and technical as well as scientific achievements, almost simultaneously fell into the possession of the Christian–Latin civilisation towards the end of the 11th century. In 1085 Alfons VI of Castilia conquered Toledo, in 1091 Roger I seized Sicily from the Arabs; while on the other hand a considerable part of greater Syria including the cultural centres between Antioch and Jerusalem, came under the rule of the Latin crusaders—also referred to as "Orient-Latins" in the literature—for approximately 200 years with interruptions, between 1099 and 1291. In the process of reception and assimilation of the sciences cultivated in the conquered and reconquered areas, the exponents of the cultural centres in the south of Italy and in Syria had a certain advantage over the western European centres. In Spain the translation activities had begun as early as in the 10th century and kept growing continuously, while the assimilation of newly acquired knowledge had already made considerable progress. The 'Orient-Latins' on their part had the opportunity to benefit from both the progress made in the European centres and, during their two hundred years of contacts with the centres of Arab–Islamic culture, from local sources and achievements which had not found their way to Europe via Spain for various reasons, including that they were too recent.

The process of translating available, mostly classical works which was cultivated in the centres of western and north-western Europe from the 10th century, having expanded considerably in the course of 150 to 200 years, eventually also reached Italy. The translations made in the southern Italian area are known thanks to the work of

[352] v. Zakarīyā' b. Muḥammad al-Qazwīnī, *Āṯār al-bilād wa-aḫbār al-ʿibād*, Göttingen 1848 (reprint, Islamic Geography, vol. 198, Frankfurt 1994), p. 374; M. Amari, *Biblioteca arabo-sicula*, Leipzig 1857 (reprint: Islamic Geography, vol. 153, Frankfurt 1994), Arabic text pp. 142–143; E. Wiedemann, *Auszüge aus arabischen Enzyklopädien und Anderes*, op. cit. pp. 413–414 (reprint, op. cit. pp. 130–131).

[353] M. Steinschneider, *Die europäischen Übersetzungen aus dem Arabischen,* op. cit. p. 13; Ch. H. Haskins, *Studies in the History of Mediaeval Science*, op. cit. p. 171; G. Sarton, *Introduction…* op. cit. vol. 2, part 1, p. 346; *L'optique de Claude Ptolémée dans la version latine d'après l'arabe de l'émir Eugène de Sicile,* ed. A. Lejeune, Leiden 1989.

M. Steinschneider,[354] [147] Ch. H. Haskins[355] and H. Schipperges.[356] With the new channel opened by the 'Orient-Latins'—which was more of an immediate connection than a route—the process of reception assumed an entirely new character. In the 12th and 13th centuries, when Arab–Islamic sciences had reached their zenith both in theory and practice, the 'Orient-Latins' bridged the distance between southern Italy and the centres of the Islamic world across the Mediterranean. The reception was no longer restricted to the translation of books, more often than not dictated by chance than by design. Under the new circumstances, even if they were often disturbed by bellicose relations, one had the opportunity to learn directly about new and old, yet unknown achievements such as scientific and technical instruments and devices, weapons or also certain institutions, and to get to know the contents of books from Arabic-speaking Christian teachers without bona fide translations. Cultural centres like Antioch, Edessa, Laodicæa (Latakia, Arabic: al-Lāḏiqīya) and Jerusalem thereby gained a leading role under the 'Orient-Latins'.

This straight-forward presentation of the phenomenon should however not create the impression that I would not be aware of the 'catastrophy-theory' quite common in the 18th and the 19th centuries, according to which the reception of Arabic sciences was predominantly a consequence of contacts resulting from the crusades.[357] Yet my opinion is comparably more nuanced, with emphasis on the fact that the crusaders, who had experienced the superiority of Arab–Islamic sciences had the opportunity to encounter the latest achievements and knowledge in the centres of the Islamic world and to transmit these to Europe, in a fairly advanced phase of the reception and over a period of 200 years. This process may be illustrated by a few examples.

The cosmographer Zakarīyā' b. Muḥammad al-Qazwīnī (b. ca. 600/1203, d. 682/1283) reports "that at the time of al-Malik al-Kāmil the Franks sent problems to Syria for the solution of these. Amongst them were medical, philosophical and mathematical questions. The scholars of Syria solved the medical and philosophical problems themselves, while they could not cope with the mathematical ones. But al-Malik al-Kāmil desired that all problems be solved and therefore sent them to Mosul [al-Mauṣil] to al-Mufaḍḍal b. 'Umar al-Abharī, our teacher who was unequalled in the science of geometry, but all the same the solution was too difficult for him. He showed the problem to master Ibn Yūnis [Kamāladdīn, d. 639/1242], who thought about it and solved it. The task is this: Take an arc, draw its chord and extend it beyond the arc; on the extended chord draw a square the area of which shall be equal to that of the segment. This is the figure:

Al-Mufaḍḍal [al-Abharī] added a proof to the solution, wrote a treatise on it and sent it to al-Malik al-Kāmil in Syria."[358]

[354] *Die europäischen Übersetzungen aus dem Arabischen,* op. cit.

[355] *Studies in the History of Mediaeval Science*, op. cit. pp. 155–193.

[356] *Die Assimilation der arabischen Medizin*, op. cit. pp. 164–188.

[357] v. H. Schipperges, *Ideologie und Historiographie des Arabismus*, op. cit. pp. 29, 37, 41, 43.

[358] al-Qazwīnī, *Āṯār al-bilād wa-aḫbār al-ʿibād*, op. cit. p. 310; the translation follows, with minor changes, H. Suter, *Beiträge zu den Beziehungen Kaiser Friedrichs II. zu zeitgenössischen Gelehrten des Ostens und Westens, insbesondere zu dem arabischen Enzyklopädisten Kemâl ed-din ibn Yûnis*, in: H. Suter, *Beiträge zur Geschichte der Mathematik bei den Griechen und den Arabern,* ed. J. Frank, Erlangen 1922, pp. 1–8, esp. p. 3 (reprint in: Islamic Mathematics and Astronomy, vol. 77, pp. 307–314, esp. p. 309).

[148] The spokesman of "the Franks" was Emperor Frederick II of Hohenstaufen (r. 1212–1250), the addressee the Aiyubid Sultan Nāṣiraddīn Muḥammad al-Malik al-Kāmil (r. 615/1218–635/1238), who had ceded Jerusalem to Frederick by an agreement in the year 626/1292. Putting aside the question of how Frederick came to or from where he got such a difficult mathematical problem, let me first give another example:

Frederick II put seven questions from the field of natural sciences to al-Malik al-Kāmil with the request to have them answered by his scholars. The Cairene juristprudent Šihābaddīn Aḥmad b. Idrīs al-Qarāfī (d. 684/1285) preserved some of the questions together with other questions on natural sciences in a special treatise called *Kitāb al-Istibṣār fīmā tudrikuhu l-abṣār*[359]. Amongst the questions posed by Frederick II were, inter alia, the following:

"1. Why does one see oars, lances and all straight bodies of which a part is submerged in clear water, as bent towards the surface of the water?"

"2. Why does one see Suhail (Canopus) larger at its rising than at its highest position, although in the south there is no moisture—which, in the case of the Sun (viz. at the corresponding altitudes) is used as an explanation (of this phenomenon)—because the southern areas are dry deserts?"[360]

As a third example from the "Sicilian questions" of Frederick II we may cite some that are of a philosophical nature. He addressed them to the Almohad sovereign ʿAbdalwāḥid ar-Rašīd (r. 630/1232 to 640/1242). The philosopher and mystic ʿAbdalḥaqq b. Ibrāhīm Ibn Sabʿīn[361] (b. 613/1216 or 614, d. 668/1270 or 669), at that time staying in Ceuta, was charged with the task of answering them. The first question put by the emperor runs thus: "Aristotle the sage teaches in all his writings the eternal existence of the world. Nobody doubts that this was his opinion. If Aristotle has proven that, what are the arguments that he used?"

The second question: "What is the purpose of metaphysics? What are the required propaedeutics if any?"

The third question: "What are categories? In which way do they serve as keys to the diverse areas of knowledge? What is their true number? Can they be increased or reduced? Which approaches to reasoning and proof should be considered in this regard?"

The fourth question: "What is the proof for the immortality of the soul if it is indeed immortal? What is the position of the sage Aristotle on this question as opposed to Alexander of Aphrodisias?"

The fifth question refers to a quote from the Prophet Muḥammad.[362]

[359] v. E. Wiedemann, *Optische Studien in Laienkreisen im 13. Jahrhundert in Ägypten,* in: Eder. Jahrbuch der Photographie (Leipzig) 27/1913/65–72 (reprint in: E. Wiedemann, Gesammelte Schriften vol. 2, pp. 710–717 and in: Natural Sciences in Islam, vol. 34, pp. 153–160); idem, *Fragen aus dem Gebiet der Naturwissenschaften, gestellt von Friedrich II., dem Hohenstaufen*, in: Archiv für Kulturgeschichte (Leipzig and Berlin) 11/1914/483–485 (reprint in: Wiedemann, Gesammelte Schriften, vol. 2, pp. 789–791 and in: Natural Sciences in Islam, vol. 34, pp. 173–175); Aydın M. Sayılı, *Al Qarāfī and his explanation of the rainbow,* in: Isis (Bruges) 32/1940–47/16–26 (reprint in: Natural Sciences in Islam, vol. 34, pp. 176–186).

[360] Translated by E. Wiedemann, *Fragen aus dem Gebiet der Naturwissenschaften,* op. cit. p. 484 (reprint in: Gesammelte Schriften, op. cit. p. 790 and in: Natural Sciences, op. cit. p. 174).

[361] C. Brockelmann, op. cit. vol. 1, p. 465, suppl. vol. 1, p. 844.

[362] v. Martin Bravmann, *Kaiser Friedrich II. und sein Verhältnis zur aristotelischen und arabischen Philosophie,* in: M. Grabmann, *Mittelalterliches Geistesleben. Abhandlungen zur Geschichte der Scholastik und Mystik*, vol. 2, Munich 1936, pp. 103–137, esp. pp. 130–131 (reprint in: Islamic Philosophy, vol. 80, pp. 275–309, esp. pp. 302–303). Further studies concerning the philosophical questions of Frederick II. in Islamic Philosophy, vol. 80 (*Ibn Sabʿīn and his philosophical correspondence with the Emperor Frederick II,* Frankfurt 1999) are as follows: Michele Amari, *Questions philosophiques adressées aux savants musulmans par l'empereur Frédéric II,* in: Jour-

[149] The questions on natural sciences, philosophy and even theology put to the Arab princes are not the only indication that the presence of the crusaders in an important part of the Islamic world had opened up an entirely new scenario for the process of becoming acquainted with local cultural assets and for their assimilation. This intellectually open atmosphere assumed a special quality with Emperor Frederick II and his personal inclinations and private encounters with sovereigns and scholars.

It is highly gratifying that in the past decade several commendable attempts have been made to investigate, in special events, the presence of the crusaders in Palestine from the viewpoint of history of science.[363] Considerable progress was made away from the previously favoured view that the crusaders were not to be taken into consideration for the process of the reception of science and technology of the Arab–Islamic world; the contributions give rise to hopes that an appropriate correction in the historiography of sciences may be achieved in the near future. When Raymond Mercier[364] in his substantial contribution comes to the conclusion that from his point of view the crusaders have to be ruled out as mediators of knowledge in "mathematical astronomy", then this is to be understood in the sense of translations of astronomical books. Yet undoubtedly many a crusader did come across one or the other of the astronomical instruments in widespread use during his stay in the Islamic world and brought such a device back to Europe on his return. Thus the 'Orient-Latins' will frequently have become middlemen for processes regarding making and using of instruments, tools, weapons or drugs which they got to know, not by reading books but through personal contacts during their stay in Syria. The positive side-effects of the crusades in the field of astronomy include, for instance, the golden planetarium that Emperor Frederick II received in the year 629/1232 as a gift from al-Malik al-Kāmil (or from Mūsā b. Muḥammad al-Malik al-Ašraf, r. 626/1228–635/1237 in Damascus). "When [150] Frederick showed his precious planetarium in which Sun, Moon and stars moved in curious harmony, in later days to particularly distinguished visitors, he loved to say that this gift from his Arab friend, the Sultan, was so dear to him, it came second in his love only to King Konrad, his son and heir."[365] Frederick kept the planetarium in Venosa.

The supposedly French type of astrolabe with the lower equatorial bar (infra II, 101) and the mechanical Franco-Gothic lunar calendar (infra II, 170) are in my assessment also likely to

nal asiatique (Paris), 5ème série 1/1853/240–274; August Ferdinand Mehren, *Correspondance du philosophe soufi Ibn Sab'în Abd oul-Haqq avec l'empereur Frédéric II de Hohenstaufen, publiée d'après le manuscrit de la Bibliothèque Bodléienne, contentant l'analyse générale de cette correspondance et la traduction du quatrième traité sur l'immortalité de l'âme,* in: Journal asiatique (Paris) 7ème série 14/1879/341–454; *Ibn Sab'în: Correspondance philosophique avec l'empereur Frédéric II de Hohenstaufen*, vol. 1: Texte arabe publié par Şerefettin Yaltkaya, Avant propos par Henry Corbin, Paris 1941 (Études Orientales vol. 8); Louis Massignon, *Ibn Sabʿīn et la critique psychologique dans l'historie de la philosophie musulmane,* in: *Mémorial Henri Basset*. Nouvelles études nord-africaines et orientales, vol. 2, Paris 1928, pp. 123–130; Esteban Lator, *Ibn Sabʿīn de Murcia y su "Budd al-ʿārif",* in: Al-Andalus (Madrid and Granada) 9/1944/ 371–417; Francesco Gabrieli, *Fredrico II e la cultura musulmana*, in: Rivista storica italiana (Naples) 64/1952/5–18; Darío Cabanelas, *Frederico II de Sicilia e Ibn Sab'in de Murcia. Las 'Cuestiones sicilianas',* in: Miscelanea de estudios árabes y hebraicos (Granada) 4/1954/31–64.

[363] e.g. *Crusaders and Muslims in twelfth-century Syria*, ed. Maya Shatzmiller, Leiden 1993; *Occident et Proche-Orient: Contacts scientifiques au temps des Croisades.* Actes du colloque de Louvain-la-Neuve, 24 et 25 mars 1997, ed. Isabelle Draelants, Anne Tihon, Baudouin van den Abeele, Louvain 2000.

[364] *East and West contrasted in scientific astronomy,* in: *Occident et Proche-Orient*, op. cit. pp. 325–342, esp. p. 340.

[365] v. Ernst Kantorowicz, *Kaiser Friedrich der Zweite,* 3rd ed., Berlin 1931, vol. 1, p. 179, vol. 2, p. 69.

have come to western Europe through channels opened up by the 'Orient-Latins'.
The investigation into instruments and techniques that have reached Europe from the Arabic area via the transmission lines of this category, must, in my view, be assigned the highest priority in the future historiography of sciences. In my view gained through intensive occupation with the subject weapons in particular, improved or invented in the Arab–Islamic area, were adopted and used as quickly as possible by the crusaders and brought to Europe with minimal delay on the transmission routes in question. This includes the winch crossbow, an improved variety of a weapon known already to the Greeks and the Romans. The decisive new element of this variant consisted in a winch which substantially facilitated the drawing of the large bow. There is historic evidence that such a crossbow was used against the crusaders in the year 647/1249 near al-Manṣūra in Egypt (infra V, 94). When in the year 636/1239 Emperor Frederick II ordered a captain sailing to Acco ('Akkā) to purchase *tres bonas balistas de torno et de duobus pedibus*, in all likelihood this also referred to the same type of crossbow (infra V, 94).
We should also mention the counter-balance trebuchet which appeared in the Arab–Islamic area in the early 13th century and soon afterwards was also used by the Europeans. It was a considerably more advanced type of catapult known already to the Greeks and the Sasanid Persians (infra V, 96).
It is highly probable that the knowledge of firearms which reached Europe towards the end of the 13th or at the beginning of the 14th century came from the Arab–Islamic area as well. If it was not transmitted directly by the crusaders, then it came to Europe on a route via southern Italy (infra V, 101).

A certain type of mariners' compass (infra III, 60) appears to have reached Europe on this route as well. It is described in an epistle, written in around 1270 by the French scholar Petrus Peregrinus, who got his sobriquet as a participant in one of the crusades. He also seems to have been present at the siege of Lucera in 1269. Frederick II had settled his Arab body guard from Sicily in this Apulian town in 1223.[366] Even at a time when less was known about the process of the reception of Arabic sciences than today, it was considered whether the new information appearing in Peregrinus' treatise might be connected with Arabic sources.[367] [151] The subjects he dealt with, such as physical magnetism, the law of inertia, and other aspects from optics, astronomy and chemistry can now be traced back to Arabic sources without difficulty. This applies also to the two types of compass described by Peregrinus (infra III, 59 ff.). The more advanced compass of Arabic navigators in the Indian Ocean also seems to have reached Europe via southern Italy in the 15th century.[368] The Genovese Christopher Columbus is known to have carried such a compass with him on his first voyage of discovery.[369]
The extant remains of illustrated Arabic manuscripts and their Latin-Hebrew translations, on automata, mechanical devices, astrolabes, clocks, weapons and the like, allow us to conjecture that, at the time of the crusades—when the zest for reading was very strong in the Islamic world—such books drew the attention of the Orient-Latins and thus also found their way to Europe. For illustrated works to have exerted an influence, understanding the accompanying text was not always necessary. Regarding future research on the process of reception of Arab–

[366] v. Erhard Schlund, *Petrus Peregrinus von Maricourt, sein Leben und seine Schriften (ein Beitrag zur Roger Bacon-Forschung)*, in: Archivum Franciscanum Historicum (Florence) 4/1911/436–455, 633–643, 5/1912/22–40, esp. pp. 450, 453, 455.

[367] v. Erhard Schlund, *Petrus Peregrinus*, op. cit. p. 643; Eberhard Horst, *Der Sultan von Lucera. Friedrich II. und der Islam,* Freiburg etc. 1997, pp. 46–49.

[368] v. F. Sezgin, op. cit. vol. 11, pp. 252, 325.

[369] ibid, vol. 11, p. 253; Heinz Balmer, *Beiträge zur Geschichte der Erkenntnis des Erdmagnetismus*, Zurich 1956, p. 79 ff.

Islamic sciences in the Christian-European culture, a comparison of surviving works from both cultural areas under this aspect would appear promising to me. While occasionally consulting Latin and Italian illustrated works such as those by Conrad Kyeser (1405), Mariano Taccola (1433), Leonardo da Vinci (1519), Georgius Agricola (1556), Agostino Ramelli (1588) or Fausto Veranzio (1615), it occurred to me that they must have been strongly influenced by Arabic sources .

The examples meant to give a certain idea of the second route of reception and assimilation of Arab–Islamic sciences via southern Italy shall conclude with the mention of three scholars whose works were the subject of recent research. They are Stephanus of Antioch (first half of the 12th c.), Leonardo of Pisa, known as Fibonacci (ca. 1170 – ca. 1240), and Theodorus of Antioch (d. 1250).

Stephanus of Antioch hailed from Pisa and went, possibly as a crusader, to Antioch where his uncle held the office of patriarch. He learned Arabic and took up the task of making a new translation of the handbook of medicine by ʿAlī b. al-ʿAbbās al-Maǧūsī (4th/10th c.), which had been rendered incompletely by Constantinus Africanus and, what is more, circulated as the latter's own work. It appears that Stephanus realised that the *Liber pantegni* was not by Constantinus Africanus only when he saw the Arabic original in Antioch (supra p. 91).[370] In another book, called *Liber Mamonis*,[371] Stephanus appears as an assimilator of Arabic sciences. In this astronomical work he does not conceal the fact that he follows an Arabic precursor, although he does not give his name. It is remarkable that numbers are expressed in Arabic numerals.[372]

[152] While in Christian scholarly circles of the 12th century rather the study of Greek and Hebrew—for the sake of biblical studies—was encouraged, Stephanus speaks of *arabica veritas* in which one finds nourishment for the body as well as for the soul.[373]

Leonardo of Pisa (Fibonacci),[374] together with Theodorus of Antioch, belonged to the circle of scholars around Emperor Frederick II and is considered to be "the first great mathematician of the Christian West". His father being the head of the merchant colony of Pisa in Bugia (Biǧāya in today's Algeria) from 1192, he had the opportunity to come into contact with Arab scholars and to travel, in the company of his father and also on his own, to Egypt, Syria, Greece, Sicily and southern France. After his return to Pisa, he composed five works on arithmetic, algebra and geometry. Although his books are not the first ones written on these subjects in the Latin language, yet they stand out with clarity and versatility, and their special importance lies in their author's treatment of linear and quadratic equations with a comprehension and lucidity unknown in Europe up to his times. There is no doubt that his sources were translations of Arabic works, and it is also not ruled out that Leonardo, during his stay in Algeria and his visit to other Arabic countries, also came across mathematical works in the Arabic original and later took them to Pisa. His position in the history of the reception and assimilation of Arabic mathematics should be seen in the fact that he acquaint-

[370] v. H. Schipperges, *Die Assimilation der arabischen Medizin*, op. cit. pp. 34–37; Ch. H. Talbot in: Dictionary of Scientific Biography, vol. 13, New York 1976, pp. 38–39; Ch. Burnett, *Antioch as a link between Arabic and Latin culture in the twelfth and thirteenth centuries,* in: Occident and Proche-Orient, op. cit. pp. 1–78, esp. p. 6 ff.

[371] Ch. H. Haskins, *Studies in the History of Mediaeval Science*, op. cit. pp. 98–103; Ch. Burnett, *Antioch as a link between Arabic and Latin culture*, op. cit. p. 13.

[372] v. R. Lemay, *De la scolastique à l'histoire par le truchement de la philologie: itinéraire d'un médiéviste entre Europe et Islam,* in: *La diffusione delle scienze islamiche nel medio evo europeo.* Convegno internazionale dell'Accademia Nazionale dei Lincei, Rome 1987, pp. 399–535, esp. pp. 471–472; Ch. Burnett, op. cit., p. 13.

[373] Ch. Burnett, op. cit. pp. 18–19.

[374] v. Kurt Vogel in: Dictionary of Scientific Biography, vol. 4, New York 1971, pp. 604–613.

ed the Latin reader with the topics and contents of his Arabic sources in surprisingly successful compositions, not without adding some lessons of his own. In doing so he certainly did not cover all the important problems and results of Arab–Islamic mathematics that were available to him. The particular merit of his presentation lies in the treatment of arithmetic and algebra on the basis of the decimal place value system.

Fibonacci was apparently the first mathematician in the West to express the concept of zero with the term *cephirum,* borrowed from Arabic *ṣifr* (which eventually became *zero* in Italian).[375] In 1202 the fraction stroke to separate the numerator from the denominator appears in his writings, from which we can assume that he was familiar with the use of this notation amongst west-Arabic mathematicians, as for instance in Abū Zakarīyā᾽ Muḥammad b. ʿAbdallāh b. ʿAiyāš al-Ḥaṣṣār[376] (6th/12th c.).[377]

Leonardo's much higher mathematical standard compared with his European contemporaries can probably be explained with the fact that, on the one hand, during his relatively long stay in Arab countries he was in the position to acquaint himself with Arabic sources that had not yet reached Europe and that, on the other hand, he had the opportunity to sharpen his insight in the matter in lectures and discussions during his contacts with Arab–Islamic mathematicians. Raymond Mercier[378] described Leonardo's exceptional situation from his point of view [153] in the following words: "The Latin world of the 12th century was not so privileged. Here the transmission was almost entirely through books, even when the Latin translations were made in Toledo, or elsewhere in Andalus. There must have been very little contact with the living mathematical practitioners in the Arabic or Hebrew speaking world. An exception appears to be provided by the 13th century mathematician Leonardo of Pisa (Fibonacci), who as we understand, had direct access to the mathematical community in Islamic North Africa, at Bijāya (modern Algeria). The brilliant creative work which he produced shows well what could be achieved in the Latin world when living teachers were involved. The history of Latin science from the 12th to the early 16th centuries is largely one of a struggle to transcend book learning. Only at the end of that long period do we observe Europeans as true masters of scientific subjects."

As the third of the scholars contributing to the reception of Arab–Islamic sciences on the route via Sicily and Italy, we shall mention Theodorus of Antioch. Unlike the two aforesaid scholars he was not from Pisa, but was a Christian Arab who had been in the service of Frederick II in Sicily as a scholar and advisor for some time. The Syrian-Christian scholar Abu l-Farağ Ibn al-ʿIbrī (Bar Hebræus, d. 1286 ce) gives an interesting biographical account which draws a vivid picture of the life and work in a community of scholars of different creeds and shows that this essential characteristic of intellectual culture in the Islamic world continued to exist even under the rule of the crusaders. Bar Hebræus' narrative[379] reads in translation:[380] "Ṯāḏurī of Antioch

[375] v. A.P. Juschkewitsch, *Geschichte der Mathematik im Mittelalter,* op. cit. p. 351.

[376] v. H. Suter, *Die Mathematiker und Astronomen der Araber und ihre Werke,* Leipzig 1900, pp. 197–198.

[377] H. Suter, *Das Rechenbuch des Abû Zakarîjâ el-Ḥaṣṣâr,* in: Bibliotheca Mathematica (Leipzig) 3rd series, 2/1901/12–40, esp. p. 19 (reprint in: Islamic Mathematics and Astronomy, vol. 77, pp. 332–360, esp. p. 339); A.P. Juschkewitsch, op. cit. p. 366.

[378] *East and West contrasted in scientific astronomy*, op. cit. p. 236.

[379] *Ta᾽rīḫ muḫtaṣar ad-duwal,* ed. Ṣālḥānī, Beirut 1890, pp. 477–478.

[380] Rendered, with minor changes, from the German version by H. Suter, *Beiträge zu den Beziehungen Kaiser Friedrichs II. zu zeitgenössischen Gelehrten*, op. cit. p. 8 (reprint op. cit. p. 314); English: Ch. Burnett, *Master Theodore, Frederick II's philosoper*, in: *Federico II e le nuove culture*. Atti del XXXI Convegno storico internazionale, Todi, 9–12 ottobre 1994, Spoleto 1995, pp. 225–285, esp. pp. 228–229.

[al-Anṭākī], a Jacobian Christian accomplished himself in the Syrian and Latin language and in the sciences of Antiquity while in Antioch, then he travelled to Mosul [al-Mauṣil] and studied under Kamāladdīn b. Yūnis the works of al-Fārābī, Ibn Sīnā, Euclid and the *Almagest*. Then he returned to Antioch, but did not stay there long because it had become clear to him that here he could not further advance his knowledge and so went to Kamāladdīn b. Yūnis at Mosul for a second time and deepened his knowledge. Then he went to Baghdad, perfected himself in the science of medicine, studied its achievements and mastered its special applications. He wanted to enter the services of Sultan ʿAlā'addīn (Kayqubād, r. 618/1220–634/1237), but the Sultan did not show any inclination. Then he went to Armenia and entered the services of Constantine, the son of King Ḥātim (Heṭum I),[381] but he found their society (their attitudes) not agreeable and therefore he travelled with an emissary of the Imbārūr (Emperor), the king of the Franks to the same, from whom he received kindnesses and in whose favours he was. He even invested him with a complete city and its surroundings…"

This versatile scholar with his well-founded knowledge of Arabic sciences seems to have assumed a prominent position in scientific life, shortly after his admission to the court of Frederick II. It seems [154] justified to assume that he contributed substantially to the mathematical, scientific and philosophical queries sent by the Emperor to al-Malik al-Kāmil or Ibn Sabʿīn (supra p. 147 ff.). In this regard it is also remarkable that Leonardo of Pisa corresponded with Theodorus on mathematical matters. Leonardo wrote him a letter which contained problems leading to indeterminate equations of the first degree. "Theodorus, in turn, sent Leonardo a problem from indeterminate analysis of the second degree which Leonardus solved in his *Liber quadratorum*".[382] No doubt Theodorus had an important part in the introduction and dissemination of Arabic works in Sicily and southern Italy. We know that he translated for the Emperor a book on falconry into Latin which is extant under the title *Moamin*[383] and largely has the character of a veterinary book. The Arabic original was probably related to the falconry book[384] which was translated into Spanish on commission by Alfonso X about a quarter of a century later. It is not surprising that the Emperor himself composed his own elegant book on the basis of the former and other sources, his own experiences and in collaboration with Arabic falconers whom he had drawn to his court—to use his own words—"at great expenses". It was entitled *De arte venandi cum avibus* ("On the Art of Hunting with Birds").[385]

3. The Route of reception via Byzantium

This route of reception of Arab–Islamic sciences led from the centre and the eastern parts of the Islamic world to Byzantium and from there to Europe. Hermann Usener[386] already became aware of manuscripts containing

[381] v. Ch. Burnett, *Master Theodore*, op. cit. p. 232.

[382] H. Suter, *Beiträge zu den Beziehungen Kaiser Friedrichs II.,* op. cit. p. 8 (reprint, op. cit. p. 314).

[383] *Die Falkenheilkunde des "Moamin" im Spiegel ihrer volgarizzamenti.* Vol. 1: *Edition der neapolitanischen und der toskanischen Version mit philologischem Kommentar* von Martin-Dietrich Glessgen, Tübingen 1996 (Zeitschrift für romanische Philologie, Beiheft 269); cf. Ch. Burnett, op. cit. p. 239.

[384] Written by Muḥammad b. ʿAbdallāh b. ʿUmar Ibn al-Bāzyār (3rd/9th c., see F. Sezgin, op. cit. vol. 6, p. 193, vol. 7, pp. 154, 329), Spanish translation *Libro de los animales que cazan*, ed. J. M. Fradejas Rueda, Madrid 1987; v. Ch. Burnett, op. cit. p. 240.

[385] Published in various editions and facsimiles; earliest edition by Carl Arnold Willemsen, *Friderici Romanorum Imperatoris Secundi De arte venandi cum avibus*, 2 vols., Leipzig 1942; facsimile edition Graz 1969, with a commentary volume by C.A. Willemsen, *Kaiser Friedrich der Zweite, Über die Kunst mit Vögeln zu jagen*, Frankfurt 1970.

[386] *Ad historiam astronomiæ symbola*, Bonn 1876.

Byzantine translations of Arabic–Persian books in European libraries a hundred and thirty years ago.[387] Subsequent research also occasionally drew attention to translations of Arabic books into Byzantine Greek as, for example, Symeon Seth's[388] translation of the collection of fables *Kalīla wa-Dimna* (end of the 11th c. CE) from the Arabic version that ʿAbdallāh Ibn al-Muqaffaʿ (d. 139/756) had compiled from the Middle Persian version, or the anonymous translation of the book on medicine, *Zād al-musāfir* of Aḥmad b. Ibrāhīm Ibn al-Ǧazzār[389] (d. 369/979), whose translator betrays the knowledge of further Arabic sources.[390]

[155] After a rather long interruption the question of the knowledge of Arab–Islamic sciences in Byzantium once again attracted the attention of historians of science, especially after Otto Neugebauer had discovered the drawing of a model of the Sun with a double epicycle in the Greek translation of an astronomical book in a Vatican manuscript.[391] While it had been established for several years that Copernicus was influenced by Arab–Islamic astronomers in his attempt to restore the principle of the uniform motion of the planets violated by Ptolemy's *Almagest,*[392] this new find provided a lead in the issue of how that influence was transmitted. After the preliminary work by O. Neugebauer[393] and E.S. Kennedy,[394] subsequent scholars took the view that the relevant Arabic and in particular also Persian books on the latest planetary theories of Islamic astronomy found their way to Europe via Byzantine versions. Since then several studies and text editions by David Pingree (Brown University), Joseph Mogenet and his successor Anne Tihon (both Louvain) have considerably expanded our knowledge about the reception of Arabic astronomy and astrology amongst the Byzantines.

In an attempt to sum up the results achieved up to 1976, Mogenet[395] asks himself regarding the attitude of the Byzantines towards Arab astronomy between the 9th and the 14th century, to what extent one might speak generally of acceptance or of resistance. With his colleagues from Louvain, he was inclined to see two distinct periods in the Byzantine attitude, the first lasting from the 9th to the 13th centuries and the second from the 13th to the 14th centuries. He argues that in the second phase a kind of renaissance in the field of science came about in which contact with Arab–Islamic sciences was decisive.[396] Yet the influence of Islamic sciences was felt also in the first phase which Mogenet calls "traditionalist" and in which astronomy had enjoyed less prominence than astrology.[397] His successor, Anne Tihon, while characteris-

[387] v. F. Sezgin, op. cit. vol. 6, p. 57.

[388] v. Karl Krumbacher, *Geschichte der byzantinischen Litteratur von Justinian bis zum Ende des Oströmischen Reiches (527–1453)*, 2nd ed. Munich 1897 (reprint: New York 1970), p. 896; G. Sarton, *Introduction…* op. cit. vol. 1, p. 771.

[389] v. F. Sezgin, op. cit. vol. 3, pp. 304–307.

[390] v. Charles Daremberg, *Recherches sur un ouvrage qui a pour titre* Zad el-Mouçafir, *en arabe*, Éphodes, *en grec*, Viatique, *en latin, et qui est attribué, dans les textes arabes et grecs, à Abou Djafar, et, dans le texte latin, à Constantin*, in: Archives des missions scientifiques et littéraires, choix de rapports et instructions (Paris) 2/1851/490–527, esp. p. 505 (reprint in: Islamic Medicine, vol. 39, pp. 1-38, esp. p. 16).

[391] v. E.S. Kennedy, *Planetary theory in the medieval Near East and its transmission to Europe,* in: *Oriente e Occidente in medioevo: filosofia e scienze*. Convegno internazionale, [Roma] 9–15 aprile 1969, Rome 1971, pp. 595–604, esp. 602.

[392] v. F. Sezgin, op. cit. vol. 6, p. 55.

[393] *Studies in Byzantine astronomical terminology,* Philadelphia 1960 (Transactions of the American Philosophical Society, vol. 50, part 2).

[394] *Late medieval planetary theory*, in: Isis (Baltimore) 57/1966/365–378.

[395] *L'influence de l'astronomie arabe à Byzance du IXe au XIVe siècle*, in: Colloques d'histoires des sciences I (1972) et II (1973). Université de Louvain, Recueil de travaux d'histoire et de philologie, série 6, 9/ 1976/45–55, esp. p. 45.

[396] ibid, p. 46.

[397] ibid, pp. 48 ff.

ing the astronomical–astrological pursuit in this first phase, comes to a somewhat more nuanced view by distinguishing two currents. The first of these currents was on a fairly elementary level. The second was characterised by the introduction of Islamic astronomical tables.[398]

The earliest evidence that we know so far for an acquaintance of the Byzantines with Arab astronomy are comments on the *Almagest* dated 1032.[399] Their anonymous author undertakes a critical comparison between Ptolemaic astronomy and that of the "moderns" (νεώτεροι), meaning the Arab astronomers.[400] [156] He uses the tables of one Ἀλὶμ who is today identified as Abu l-Qāsim ʿAlī b. al-Aʿlam al-Baġdādī[401] (d.375/985).[402]

The second oldest testimony dates from around 1072. It is an anonymous Greek compilation from the *Zīğ* by Ḥabaš al-Ḥāsib[403] (d. end of 3rd/9th c.), the commentary by Aḥmad b. al-Muṯannā[404] (5th/11th c.) on the *Zīğ* of Muḥammad b. Mūsā al-Ḫwārizmī[405] (1st quarter of the 3rd/9th c.) and from an Arabic astrological book.[406] The most significant feature of this manuscript seems to be that the sine and versed sine functions occur here for the first time in a Greek text (going back to the *Zīğ* of Ḥabaš).[407]

A more recent compilation which is quite illuminating for our topic dates from the end of the 12th century and is found in the Codex Vat. gr. 1056.[408] In this compilation of predominantly astrological content the names of roughly twenty Arab, Indian and pseudo-Indian authors are mentioned.[409] Explicitly cited are al-Ḫwārizmī, Ḥabaš al-Ḥāsib, Kūšyār b. Labbān and the ākimite* tables by ʿAlī b. ʿAbdarraḥmān Ibn Yūnis. While studying the star tables in this compilation, Paul Kunitzsch[410] found "indisputable evidence of Arabic-Islamic origin". With regard to the stellar nomenclature he noticed[411] that "although they were all designated with Greek expressions," these were "frequently not the actual Greek, i.e. Ptolemaic names but literal translations of Arabic ones."

The compilation also contains the translation of an Arabic treatise on the astrolabe in which several Arabic technical terms were left untranslated and rendered in Greek transliteration (as κότπ = *quṭb*).[412]

In this connection we should also mention the only known "Byzantine" astrolabe.[413] According

[398] *Les textes astronomiques arabes importés à Byzance aux XIe et XIIe siècles*, in: *Occident et Proche – Orient: Contacts scientifiques au temps des Croisades*, op. cit. pp. 313-324, esp. p. 316.

[399] J. Mogenet, *Une scolie inédite du Vat. gr. 1594 sur les rapports entre l'astronomie arabe et Byzance*, in: Osiris (Brügge) 14/1962/198–221.

[400] Anne Tihon, *L'astronomie byzantine (du Ve au XVe siècle)*, in: Byzantion (Brussels) 51/1981/603–624, esp. p. 611.

[401] v. F. Sezgin, op. cit. vol. 6, pp. 215-216; Raymond Mercier, *The parameters of the Zīj of Ibn al-Aʿlam*, in: Archives internationales d'histoire des sciences (Rome) 39/1989/22-50.

[402] Anne Tihon, *Sur l'identité de l'astronome Alim*, in: Archives internationales d'histoire des sciences (Rome) 39/1989/3-21.

[403] v. F. Sezgin, op. cit. vol. 6, pp. 173-175.

[404] ibid, p. 142.

[405] ibid pp. 140-143.

[406] v. Otto Neugebauer, *Commentary on the astronomical treatise Par. gr. 2425*, Brussels 1969; Alexander Jones, *An eleventh century manual of Arabo-Byzantine astronomy,* Amsterdam 1987; J. Mogenet, *L'influence de l'astronomie arabe à Byzance*, op. cit. pp. 49-50; Anne Tihon, *Les textes astronomiques arabes importés a Byzance,* op. cit. pp. 316, 318.

[407] Anne Tihon, op. cit. p. 318.

[408] *Catalogus codicum astrologorum graecorum*, vol. 5, part 3, Brussels 1904, pp. 7-64.

[409] v. Anne Tihon, *L'astronomie byzantine,* op. cit. p. 612; idem, *Tables islamiques à Byzance*, in: Byzantion (Brussels) 60/1990/401-425, esp. pp. 405-413.

[410] *Die arabische Herkunft von zwei Sternverzeichnissen in cod. Vat. gr. 1056*, in: Zeitschrift der Deutschen Morgenländischen Gesellschaft (Wiesbaden) 120/1970/281-287, esp. p. 282.

[411] ibid, p. 282.

[412] v. Anne Tihon, *Tables islamiques à Byzance,* op. cit. p. 406.

[413] v. O. M. Dalton, *The Byzantine astrolabe at Brescia*, in: Proceedings of the British Academy, vol. 12, London

to an inscription engraved on the back, the instrument, preserved in the Museo dell'Età Cristiana in Brescia, is supposed to have been made for a consul of Persian origin by the name of Sergios. It can be considered as certain that the Byzantines used the astrolabe for the observation of celestial constellations in the 11th century, but because of certain features we should be reluctant in calling this instrument [157] "Byzantine". Firstly, the fixed star λυρα (Vega) is represented in the Arabic manner in the form of a bird (*an-nasr al-wāqiʿ* = the descending eagle), which was known in the West from the 10th century.[414] Secondly, the latitude of Byzantium (= Constantinople) being indicated as 41° on the disc casts suspicion on the date of the astrolabe. That is because the latitude of Byzantium was registered at 43° in the Ptolemaic geography and 45° with the early Arabic geographers and corrected to 41° only towards the end of the 13th century (the modern value is 41°02'). Thirdly, on the back of the mater a quadruple tangent quadrant is engraved which overlaps the scale on the rim, thus creating the impression that it was added by a later hand, especially in view of the fact that the tangent function, known since Ḥabaš (3rd/9th c.), begins to appear in the tangent quadrants on the back of astrolabes only from the first half of the 11th century. That the names of the fixed stars correspond to those of the *Almagest* rather than Arabic does not provide a clue to the age of the astrolabe. The Byzantines has been familiar with the *Almagest* and its content for a long time. However, the precession value of 1 for 66 years on which the positions of the fourteen stars on the rete are based is Arab-Islamic, not Greek. On the whole the astrolabe is Arab-Islamic in its style and its individual elements, only the language of the engraved names and other inscriptions is "Byzantine". Thus it reflects the heterogeneous and anachronistic character of the contemporary Byzantine astronomical writings.

After a fairly successful introduction of Arabic language-based astronomy in Byzantium in the course of the 11th and the 12th centuries, the Latin crusade kingdom in Constantinople (1204-1261) not only interrupted any further development, but it also obliterated the body of writings already accomplished at that time.[415] Yet it did not take long until around the turn of the 13th to the 14th century new interest in Arabic-Persian science manifested itself. This time the route to Constantinople came from the east.

Immediately after the conquest of Baghdad in the year 656/1258, Hülegü, the grandson of Cengiz Ḫān, settled in the city of Maragha, roughly 30 km to the south-east of Lake Urmia, and had a grand observatory built under the direction of the polymath Naṣīraddīn aṭ-Ṭūsī which was furnished with special observation structures (infra II, 28 ff). At the time of the Mongols, Maragha had a significant Christian population segment and maintained busy traffic with the city of Trebizond (Trabzon) on the Black Sea (still under Byzantine rule) and with Constantinople via Trebizond. The interchange with these cities increased when Abaqa Ḫān, the successor of Hülegü, made Tabrīz his capital in the year 663/1265. Tabrīz developed into an important centre of sciences when the universal scholar Rašīdaddīn Faḍlallāh aṭ-Ṭabīb (d.718/1318, supra, pp. 58, 61) was grand vizier there under the Ilkhāns Ġāzān (694/1295-703/1304) and

1926, pp. 133-146, 3 pictures; R. Gunther, *The Astrolabes of the World,* op. cit. pp. 104-108; Burkhard Stautz, *Die früheste bekannte Formgebung der Astrolabien*, in: *Ad radices*. Festband zum fünfzigjährigen Bestehen des Instituts für Geschichte der Naturwissenschaften der Johann Wolfgang Goethe-Universität Frankfurt am Main, ed. Anton von Gotstedter, Stuttgart 1994, pp. 315-328, esp. pp. 319-320; idem, *Die Astrolabiensammlung des Deutschen Museums und des Bayrischen Nationalmuseums*, München 1999, p. 11; A. Tihon, *Les textes astronomiques arabes*, op. cit. p. 323

[414] Paul Kunitzsch and Tim Smart, *Short guide to modern star names and their derivations*, Wiesbaden 1986, pp. 43-44.

[415] . v. A. Tihon, *Les textes astronomique arabes*, op. cit. p. 324.

Ölǧeitü (703/1304-716/1316). Rašīdaddīn, one of the foremost figures in cultural history, not only became a legend of his times, but personally contributed much in making Tabrīz a metropolis and a centre of trade and sciences in which scholars from the East and West were to find a home and representatives of diverse cultures a meeting place. His surviving works convey a vivid [158] picture of the cultural and scientific life in the city.

About the quarter of the city called Rabʿ-i Rašīdī or Šahristān-i Rašīdī that Rašīdaddīn himself had built, the deed of foundation, which recent research has made known, provides detailed information. The Austrian Orientalist Karl Jahn[416] who, from the 1940s, devoted himself entirely to research into the life and work of Rašīdaddīn, reports on this document, inter alia: "Thus it follows from this document that the maintenance of the Rabʿ-i Rašīdī was secured through the income of various pious foundations which Rašīd al-Dīn had established in Iran and also in Anatolia. But of particular interest is the information about the organisation of the Rašīd quarter. According to it, there lived and worked for payment under the supervision of the endowment administration, a large number of artists and artisans, who belonged to all kind of nations, lived and worked for remuneration under the supervision of the foundation council. Aside from a large number of Turks, most of them were either Greek, Georgian, Armenian, Indian, Russian, African and some belonged to still other nations…" The teaching and research institutions had "6000-7000 students from all parts of the Ilkhanid empire studying at public expense, and more than 400 scholars who lived in their own quarters and were in the position to devote themselves to teaching and research unburdened by the troubles of everyday life."[417]

Further references to the important role of the city of Tabrīz in trade and sciences contributed to by Rašīdaddīn are found in his correspondence[418] with important people of the Islamic and non-Islamic world. We learn from it that in the Rabʿ-i Rašīdī he had designated quarters for the various ethnic groups and that he had charged his son Ǧalāladdīn, who was governor of a region in Asia Minor, with persuading fourty or so Greek families to settle in the district destined for the Byzantines. One discovers further that Constantinople and Venice used to pay tributes to the Ilkhāns which Rašīdaddīn used for the alimentation of the students.[419]

A further testimony to the importance of Tabrīz at that time was discovered by Z. V. Togan in the middle of the previous century in the scientific "Questions and Answers" (*al-Asʾila wa-l-aǧwiba)* from the correspondence of Rašīdaddīn. These shed light the close contacts— to an extent which had not hitherto been known— in the field of science between Byzantium and the empire of the Ilkhāns. Thus a Byzantine philosopher and physician in the service of Rašīdaddīn translated his answers to questions of the Basileus (probably Andronikos II Palaiologos, r. 1282-1328) from the Persian into Greek. He also took pains to give the emperor an idea of Rašīdaddīn's extraordinary rank in the sciences by stating that "Plato, Aristotle and the other great [Greek] philosophers, if they lived today,

[416] *Täbris, ein mittelalterliches Kulturzentrum zwischen Ost und West*, in: Anzeiger der Österreichischen Akademie der Wissenschaften, Philologisch-historische Klasse 105, Nr. 16, Vienna 1968, pp. 201-211, esp. pp. 208-209.

[417] ibid, p. 211.

[418] *Mukātabāt-i Rašīdī*, ed. M. Šafīʿ, Lahore 1947, p. 63, cf. Z. V. Togan, *Ilhanlılarla Bizans arasındaki kültür münasebetlerine ait bir vesika* (*A document concerning cultural relations between the Ilkhanide and Byzantiens*), in: Islâm Tetkikleri Enstitüsü Dergisi (Istanbul) supplement to vol. 3 (1966), p. 1*-39*, esp. p. 2*.

[419] *Mukātabāt-i Rašīdī*, op. cit. p. 319; Z. V. Togan, op. cit., p. 2*.

would be proud to be counted amongst his disciples."[420]

[159]The "Questions and Answers", preserved in an Arabic and a Persian version, are predominantly of philosophical, theological and medical content. The Persian redaction was published in facsimile in 1966 with a brief study by Z. V. Togan. No in-depth study of the correspondence is known to me.

Since the attempt by H. Usener (supra p. 154), recent research in the history of Byzantine sciences has concentrated mostly on the fields of astronomy and astrology. The studies from the second half of the 20th century have informed us, above all, about the vogue of translations of astronomical works from the Persian that occurred in the first half of the 14th century. Many of the translated works have meanwhile been edited or examined.[421]

In 1947, George Sarton called the translation movement from the Persian to the Greek "Persian renaissance", which could also be called "Arabic [renaissance]."[422] Karl Krumbacher[423] saw in it "one of the most remarkable examples of literary retro-movement", and concluded that only through Arabic-Persian mediation had the Greeks come to know the wisdom of their own ancestors. Joseph Mogenet[424] speaks of a kind of renaissance in the field of science during the 13th and the 14th centuries in which the contacts with the Arabic-Persian sciences were of great importance.

The hitherto known astronomical works of the Byzantines,–whose authors built upon the works translated from the Persian with their tables, descriptions of astrolabes etc.–actually reflect more than merely a literary revival movement as held by Krumbacher. However, it is conspicuous that none of the works mentioned, with the exception of the anonymous manuscript discovered by Neugebauer in the Vatican, refers to the new non-Ptolemaic planetary models discussed by Persian and Arabic astronomers in the second half of the 13th century and later. It has long since been proved (supra p. 53 ff) that some of these new planetary theories reached eastern Europe in the first half of the 15th century[425] at the latest and came to be known to Copernicus. The verdict[426] that the Byzantine side showed a lack of criticism and of deeper understanding of Arabic-Islamic astronomy and these shortcomings my be the true reason why Arabic astronomy never established itself firmly amongst the Byzantines. What is more, quite a few Byzantines obstinately held fast to the restoration of Ptolemaic astronomy.[427]

The importance of this third route of reception of Arabic-Islamic sciences was by no means limited to the translation of Persian works into Greek. Personal contacts between Italy, Middle and Eastern Europe and Persia increased the potency of the reception and made it possible for the latest achievements of the eastern Islamic world to reach the West without much delay. Thus, for instance, the advanced rainbow theory of Kamāladdīn al-Fārisī came [160] very probably on this route to the knowledge of Dietrich of Freiberg (infra III, 169 ff) around the first decade

[420] Rašīdaddīn, *al-As'ila wa-l-ağwiba*, MS Istanbul, Ayasofya 2180, 264b-265a; Z. V. Togan, *Ilhanlılarla Bizans arasındaki kültür münasebetlerine ait bir vesika*, op. cit. p. 5.

[421] v. F. Sezgin, op. cit. vol. 6, pp. 56-57; Anne Tihon, *Les tables astronomiques persanes à Constantinople dans la première moitié du XIV siècle*, in: Byzantion (Brussels) 57/1987/471-487, 4 illustrations; idem, *Tables islamiques à Byzance,* in: Byzantion (Brussels) 60/1990/401-425; idem, *Traités byzantins sur l'astrolabe*, in: Physis (Florence) 32/1995/323-357.

[422] G. Sarton, *Introduction* ... op. cit. vol. 3, part 1, p. 63.

[423] *Geschichte der byzantinischen Litteratur*, op. cit. vol. 1, p. 622.

[424] *L'influence de l'astronomie arabe à Byzance du IXe au XIVe siècle*, op. cit. p. 54.

[425] v. F. Sezgin, op. cit. vol. 6, p. 56.

[426] Anne Tihon, *Un traité astronomique chypriote du XIVe siècle*, in: Janus (Leiden) 64/1977/279-308, 66/1979/49-81, 68/1981/65-127, esp. p. 109.

[427] ibid, p. 109.

of the 14th century. We can also imagine that the *Kitāb aš-Šakl al-qaṭṭāʿ* by Naṣīraddīn aṭ-Ṭūsī (d. 672/1274) in which he established trigonometry as an independent discipline reached Europe on this route where it gave rise to the *De triangulis omnimodis* of Johannes Regiomontanus (1436-1476) (infra III,135 ff.). Naṣīraddīn aṭ-Ṭūsī spent the last sixteen years of his life in Maragha, where he led the newly founded observatory, and both Maragha and Tabrīz were still frequently visited by Byzantine and other Christian travellers to Asia in the 14th century. In this connection it is illuminating that an original celestial globe from the Maragha observatory was brought to Europe quite early and was kept in Dresden from 1562 (infra II, 52). With our assumption that Naṣīraddīn's trigonometry book reached the West via Byzantium we do not necessarily mean to imply that it was already translated there. From when Constantinople was threatened and ultimately conquered by the Ottomans, new paths opened up with branches leading to Rome, northern Italy, eastern and central Europe. Books in the original and in translations as well as instruments and maps were transported along these routes, but most notably a spirit of hostility against Islam on the one hand and the idea of reinstatement of the hegemony of the old Greek sciences on the other. The most notorious character amongst these zealots was Cardinal Bessarion, the former patriarch of Constantinople. During his travels across Europe he also met G. Peuerbach and J. Regiomontanus in Vienna and instigated the latter to revise Ptolemy's *Almagest*. The fac that this revision predominantly conveys the achievements of Arab astronomers shows us that Bessarion tried in vain to turn back the wheel of the history of science.[428]

[428] v. F. Sezgin, op. cit., vol. 6, p. 58.

Conclusion

At first a short introduction was envisaged in order to give the user of the present Catalogue an overall idea, based on the current research, of the position of Arabic-Islamic sciences in the universal history of sciences. While attempting this, I was conscious that such an undertaking is connected with all sorts of pitfalls. On the one hand, the research on the subject, despite a relatively long development, is still at such an early stage that one could believe to be able to make a relatively adequate presentation on the basis of the results achieved so far that are within one's grasp. On the other hand, what has been achieved by research until now is so voluminous that with a first attempt one runs the risk of being able to grasp and transmit only a part. Added to this there are the difficulties connected with the selection of the topics and the problems to be included. Moreover, two conflicting feelings accompanied me from the beginning of the attempt. One of them states that the insights gained so far cannot be dealt with in the scope of a brief introduction, the second consists of the fear that through a more detailed treatment of this theme the further revision of the volumes on geography and literature of my *Geschichte des arabischen Schrifttums* prepared approximately fifteen years ago and ready in rough copy would suffer another delay. Therefore I gave up a detailed discussion of the process of assimilation of Arabic-Islamic sciences in the Occident beyond the 13th century which would have allowed me an exhaustive comparison between the two cultures in respect of their basic procedures or basic values of scientific endeavours like the art of experimenting, continuous practical observation for long periods in astronomy **[161]**, the importance of criticism, the custom of naming sources precisely, the acknowledgement of the achievements made by predecessors, the concept of the law of evolution and other topics. These aspects are to be dealt with in the third

section that follows, wherein the question is posed about the end of creativity in Islam.

Through the conquest of a substantial part of the region of the Mediterranean and of Persia in the first half of the first century of Islam (7th c. AD), the Muslims were able to bring most of the important cultural centres under their rule. One cannot rate highly enough the great coincidence, which is significant from the viewpoint of history of science, that the carriers of culture of those times, whether Christians, Jews, Sabaeans or Zoroastrians, and regardless of whether they were converted or not, could live together with the conquerors and continue their scientific work, and were even encouraged by their new rulers in such work. Largely on the basis of this harmonious co-existence of people belonging to different cultures and religions, there arose in the Islamic world a teacher-pupil-relationship the like of which was unknown in the European Middle Ages. It resulted in fast and thorough learning, prevented plagiarism, and was for centuries one of the most important characteristics of Islamic scholarship. That the Latin world in its process of reception and assimilation lacked this strength of the Arabic-Islamic world until the beginning of the 16th century was perhaps first pointed out by Raymond Mercier.[429]

In the 2nd/8th century we already encounter a fully developed Arabic philology that could provide the necessary tools for the formation or diversification of new disciplines. Without the interplay with a well developed philology the well known perfection and self confidence we know from the translation of Greek works into Arabic from the first half of the 3rd/9th century would have been impossible.

It is one of the most amazing features of the history of science that in chemistry-alchemy after just a single century the phase of reception and assimilation was already over and creativity could begin.

The process of reception and assimilation in most of the other disciplines of the natural sciences had advanced so far towards the end of the 2nd/8th century that they also stood on the threshold of creativity. The qualitatively high and quantitatively broad development of the Arts went hand in hand. Such an upward swing would certainly have been inconceivable had Islam not, as Franz Rosenthal stressed in another context "from the very beginning, emphasised the role of knowledge (ʿilm*)* as the main driving force of religious life and thus of entire human life" (supra p. 5). But the quick appropriation of foreign knowledge systems and their further elaboration has also substantially to do with the fact that persons belonging to the older cultures could feel accepted by the Muslims and could feel valued from the beginning.

As far as we can judge from the results of research to date, the creativity seems to have begun in the fields of the natural sciences and the exact sciences around the middle of the 3rd/9th century – in individual cases even earlier – and the process of reception and assimilation seems to have been completed towards the end of the century. Creativity continued in all fields with an intensity that can be traced, although it was not always linear, and continued even with the establishment of new fields of sciences until the 15th century – in individual cases also up to the end of the 16th century.

[162] In an early phase of the research into the history of the Arabic-Islamic sciences, there developed the habit of speaking of a "golden period" of these sciences which was said to have ended as early as in the first half of the 5th/11th century. Together with this notion, another idea became current according to which a period of stagnation in Arabic-Islamic sciences began with the overthrow of the Abbasid empire by the Mongols in the year 656/1258. Although both the ideas are not confirmed by the latest research, they are still mentioned now as be-

[429] *East and West contrasted in scientific astronomy*, in: *Occident et Proche-Orient*, op. cit., pp. 325-342, esp. pp. 325-326.

fore. In reality, the 13th, the 14th and even the 15th centuries turn out to be an era of numerous discoveries, of inventions and of the establishment of new disciplines of knowledge in Arabic-Islamic sciences.

When the sciences in the Arabic-Islamic world were still in the first phase of their upward movement, they began to spread from Spain to other parts of Europe in the second half of the 4th/10th century. The designation of this current, lasting several centuries, as reception and assimilation of Arabic sciences in Europe came into use in the second half of the 20th century. Heinrich Schipperges, who could be considered the father of this designation, used it almost with the same meaning as the term "Arabism".[430] The fluctuating assessment of the value of Arabic-Islamic sciences for Europe, as can be traced in its contradiction through the centuries, continues still. We cannot say that research has not advanced far enough to give the historian of science enough relevant material for a more objective view of the factual position; but the anti-Arabism that already began towards the end of the 13th century is still felt and is again strengthened through the Euro-centric attitude of the last three hundred years. We owe to Heinrich Schipperges an instructive description of the anti-Arabism. He called his work that appeared in 1961[431] a preliminary study; but a better one has not yet appeared. He describes the phenomenon of Arabism itself, which is distinguished from the term Arabic studies, as a "manifestation that has greatly influenced the centuries and is still exercising influence without which we will not understand the structure of the modern world."[432]

In several studies, Schipperges attempted to approximately demarcate the various stages of Arabism – he sees its end after 1700[433] – without excluding its continued effect in the field of medicine up to the 19th century.[434] At this place we may mention that Schipperges, while doing research in Spanish libraries in 1967, discovered among 200 Latin manuscripts no less than 60 titles by hardly known Spanish physicians and could convince himself that the "Spanish Arabists" of the 13th to the 17th centuries had "not only had an influence on the Iberian schools but beyond that on the European universities as well."[435] In the course of another research trip through Spanish libraries he found "in the Spanish region until far into the 17th and the 18th centuries a Galenism that oriented itself towards Avicenna."[436]

[163] Deviating from Schipperges' finely differentiated stages of "European Arabism", when we now search, in a broader periodisation, the beginnings of that stage in which creativity could be noticed in Europe as a consequence of the sufficiently long reception and assimilation of Arabic-Islamic sciences, then we are led to the beginning of the 16th century. I am aware that the mere mention of such a statement will agitate some people. However, research into the history of Arabic-Islamic sciences has advanced so much since the commendable pioneering work by the indefatigable scholars Jean-Jacques Sédillot, Louis-Amelie Sédillot, Joseph-Toussaint Reinaud, Franz Woepcke, Michael Jan de Goeje, Eilhard Wiedemann, Carl Schoy, Heinrich Suter and others from the 19th century and the first third of the 20th century, and this research has furnished us with so much convincing material that we – true to our responsibility

[430] H. Schipperges, *Arabische Medizin im lateinischen Mittelalter*, Heidelberg 1976, p. 149.

[431] *Ideologie und Historiographie des Arabismus*, Wiesbaden 1961.

[432] ibid, p. 5.

[433] v. e.g. *Handschriftenstudien in spanischen Bibliotheken zum Arabismus des lateinischen Mittelalters*, in: Sudhoffs Archiv (Wiesbaden) 52/1968/3-29, esp. pp. 27-28; idem, *Arabische Medizin im Mittelalter*, op. cit., p. 150.

[434] *Handschriftenstudien*, op. cit., p. 22.

[435] ibid, p. 27.

[436] *Zur Wirkungsgeschichte des Arabismus in Spanien*, in: Sudhoffs Archiv 56/1972/225-254, esp. p. 248.

– must make every attempt to bring about a revision of the prevailing assessment of our subject in the historiography of science.

With our view of placing the onset of creativity in Europe at the beginning of the 16th century, we of course deviate from the common path taken in the historiography of sciences, which enumerates a series of achievements as the accomplishments of the so-called "Early Renaissance," to which belong the origin of universities in Europe, the application of mathematics to problems of natural sciences by Roger Bacon (ca. 1219- ca.1292), the first correct explanation for the formation of the rainbow by Dietrich of Freiberg (ca.1250-ca.1310), or also the achievements ascribed to Levi ben Gerson (1288-1344) of the invention of the camera obscura, of the spherical sine theorem and of the proof for the postulate of parallels, as well as the establishment of trigonometry as an independent discipline by Johannes Regiomontanus (1436-1476).

As far as the foundation of universities is concerned, it is not surprising that the oldest of them originated in the first third of the 13th century in centres of the assimilation of Arabic-Islamic sciences like Naples (1224), Padua (1222), Paris (1219), Toulouse (1229), Montpellier (1239) or Palencia (1212).[437] In his study, written from the perspective of a non-Arabist, Herbert Grundmann[438] came to the conclusion that "the universities arose spontaneously, without a conscious model, from the urge for knowledge", after he had pointed out that they "have become so common that we all too rarely consider how uncommon, remarkable and in need of explanation their origin must have been in the middle of the Occidental Middle Ages."[439] Schipperges[440] commented on this as follows: "We can agree with Grundmann only to a limited sense when he speaks of universities arising without a conscious model, spontaneously, out of the urge for knowledge. Even if there had been no Greek, Roman or Byzantine model, – why did nobody ask about the Arab model, about that mediator culture of the Middle Ages, the genuine catalyst that secured and actualised the heritage of Antiquity for the universities?" Of Arab models Schipperges[441] mentions the al-Madrasa an-Niẓāmīya, founded in 457/1065 in Baghdad:

"We have detailed plans of similar school buildings. They were laid out as a square with a garden, [164] contained lecture halls and conference rooms, a central library with all technical divisions, depots and magazines … The appointment of professors was done by ministerial order. Inaugural lectures took place in the presence of high dignitaries followed by a disputation in honor of the newly appointed professor, often also in the presence of the Caliph. Afterwards the new docent gave an installation banquet. In the teaching itself, it was these professors who had to organize the typical scholastic discussions, so-called repetitors functioned as assistants. It was the Niẓāmiyya in Baghdad once again which introduced, since the middle of the 11th century, a general plan into Islamic institutions of higher learning."

"The reflection of this important school foundation can be observed quite exactly in the case of a later Baghdad academy, the famous Madrasa Mustanṣiriyya. It was founded in 1227 by Caliph al-Mustanṣir. The building, situated on the left bank of the Tigris, was completed in 1232 and consisted of four large complexes, among them a special building for the teaching of medicine,

437 v. H. Schipperges, *Einflüsse arabischer Wissenschaft auf die Entstehung der Universität*, in: Nova Acta Leopoldina (Halle) 27/1963/201-212, esp. p. 210.

438 *Vom Ursprung der Universität im Mittelalter*, Berlin 1957 (Berichte über die Verhandlungen der Sächsischen Akademie der Wissenschaften zu Leipzig. Philol.-histor. Klasse Bd. 103, Heft 2), p. 63; H. Schipperges, *Einflüsse arabischer Wissenschaften*, op. cit., p. 201.

439 H. Grundmann, *Vom Ursprung der Universität*, op. cit., p. 17.

440 *Einflüsse arabischer Wissenschaft*, op. cit., p. 211.

441 ibid, pp. 108-109, with reference to Asad Talas, *L'enseignement chez les Arabes. La madrasa Nizamiyya et son histoire*, Paris 1939.

pharmacy and natural sciences. Annexed to it were a hospital, a central kitchen, baths and depots" (cf. the chapter on architecture, vol. V, 65 ff.).

"Among the subjects of instruction the strong accent on the exact sciences is noticeable: besides religion and languages, as subjects of instruction, mathematics and medicine are especially mentioned; and enumerated individually are geometry, nature studies, pharmacy and hygiene. The importance that was attributed to such a school can be seen from the fact that, although it was partially destroyed at the time of the invasion by the Mongols in 1258, it was soon rebuilt and reorganised by the conquerors themselves".

Schipperges [442] continues: "There can be no doubt that such renowned academies became known in the Occident in their outer forms also, given the stormy reception of teaching material since the middle of the 12th century and the lively west-east peregrination of the young scientists."

In Europe, there were various ways and paths to learn about the universities of the Arabic-Islamic world. However, for the appropriation of this institution, receptivity and maturity were required that had been achieved in the Occidental-Christian world through the reception and assimilation of Arabic-Islamic sciences. We find the most convincing clue for this in the university founded by Emperor Frederick II in Naples in 1224. It was the first state university[443] in Europe and thus corresponded with its predecessor an-Niẓāmīya in Baghdad and many others in the Islamic area. That Frederick II was in close contact with the Arabic-Islamic world and an admirer of and adherent to its culture and science is widely known (supra p. 148 ff).

The second point mentioned above refers to Roger Bacon. Not only in his case the historiography of science is burdened with long outdated ideas originating under Euro-centric views. The designation of Bacon as the founder of the application of mathematics to problems of natural sciences is conferred at the cost of his Arab predecessors, among them Ibn al-Haiṯam.[444] R. Bacon established relationships to Arab "models without reaching up to them when he made his general observations concerning the experiment [165] as the basis for research in the natural sciences. However, he did not invent this method, but only presented it systematically, although in a somewhat different interpretation than the Arabs did. He is not the creator of the experimental method just as Bacon of Verulam [1561-1626] is not the creator of the inductive method, even though the English would like to ascribe both to their compatriots."[445] Towards the end of the 19th century P. Mandonnet[446] remarked that Roger Bacon had taken all his scientific ideas from the Arabs.

"Despite his critical attitude, Roger Bacon was decisively influenced by the Arab thinkers, particularly by Averroes and Avencebrol. He was unfairly made the forerunner of the modern scientific methods; Roger's indecision may have influenced this assessment rather than an independent intellectual attitude" wrote H. Schipperges in 1961.[447]

442 *Einflüsse arabischer Wissenschaften*, op. cit., p. 209.

443 H. Grundmann, *Vom Ursprung der Universität,* op. cit., pp. 13-14.

444 v. E. Wiedemann, *Roger Bacon und seine Verdienste um die Optik*, in: *Roger Bacon Essays*, contributed by various authors, Oxford 1914, pp. 185-203, esp. pp. 186-187 (reprint in: E. Wiedemann, *Gesammelte Schriften*, vol. 2, pp. 770-788, esp. pp. 771-772).

445 E. Wiedemann, *Die Naturwissenschaften bei den orientalischen Völkern,* in: *Erlanger Aufsätze aus ernster Zeit,* Erlangen 1917, pp. 49-58, esp. p. 58 (reprint in: E. Wiedemann, *Gesammelte Schriften*, vol. 2, pp. 853-862, esp. p. 862 and in: Historiography and Classification of Science, vol. 16, pp. 261-270, esp. P. 270).

446 *Les idées cosmographiques d'Albert le Grand et de S. Thomas d'Aquin et la découverte de l'Amérique*, in: Revue Thomiste (Paris) 1/1893/46-64, 200-221; F. Sezgin, op. cit., vol. 10, p. 217.

447 *Ideologie und Historiographie des Arabismus*, op. cit., p. 11.

On the question of the excellent theory of the rainbow which became known in Europe through Dietrich von Freiberg in the first decade of the 14th century, but which originates in reality from the Arabic-Islamic world, I restrict myself to a reference to the relevant remarks on the subject in this introduction (supra p. 56 ff.) and in the chapter on optics in our Catalogue (infra III, 169 ff.).

As far as the achievements ascribed to Levi ben Gerson (1288-1344) are concerned (supra p. 163), we may mention that in the case of the camera obscura[448] he followed Ibn al-Haiṯam (infra, the chapter on optics, III, 184 ff.). As regards the spherical sine theorem,[449] he must have used sources which brought him in contact with his Arabic predecessors (infra III, 135 ff.) and with his attempt to prove the postulate of the parallels (infra III, 126 ff.) that he undertook as the first person in Europe, he was once again dependent on his predecessor Ibn al-Haiṯam.[450]
In the case of the alleged establishment of trigonometry as an independent discipline through Johannes Regiomontanus, we point out that he had Naṣīraddīn aṭ-Ṭūsī as his predecessor (supra p. 160).

If we leave aside the advance made by Gutenberg around 1450 with the development of book printing, then there remains the decision by Copernicus in favour of the heliocentric system as another sign of Occidental creativity. The heliocentric system had already been thought of by Aristarchus (3rd c. BC) and Seleukus (2nd c. BC) and it had been also taken into account by Arabic astronomers and philosophers who, however, partly could not decide in the affirmative and were partly content with the rotation of the Earth (supra p. 20). At all events one should not forget that the Copernican system, in the words of Carlo Alfonso Nallino,[451] "remained for longer than a century a purely philosophical question – without interest for observational astronomy which could not have brought to its support a single decisive or important reason". Also the most important European astronomer, Tycho **[166]** Brahe (1546-1601) could not follow this system. He was content with the notion that the upper planets were satellites of the Sun and that the Sun together with the Moon circled the Earth.[452] We have already mentioned that Copernicus (1473-1543) stood in a tradition of dependence on Arab astronomers and appropriated their planetary models. In observational astronomy, progress became possible only when, in the second half of the 16th century, observatories began to be placed in the service of astronomy, a feature that had been common in the Arabic-Islamic world already for six hundred years. It was Tycho Brahe who achieved the first known advance with his discovery of the third inequality or variation of the Moon. But we may mention in passing that about half of this variation was already included in the equation of the anomaly of the Moon by Arab astronomers.[453]

Of course, the progress made by Copernicus in theoretical and by Tycho Brahe in observational astronomy does not mean that the era of dependence on Arabic-Islamic scholars had come to an end. Even Johannes Kepler (1571-1630) was still dependent on his Arabic-Islamic predecessors. From the field of astronomy we may mention that the deductive explanation given by the Andalus-Arab scholar az-Zarqālī (end of the 5th/11th c.) of the orbit of Mercury as an oval resembles the explanation of the orbit of Mars

[448] v. G. Sarton, *Introduction*, vol. 3, p. 602.

[449] A. von Braunmühl, *Vorlesungen über Geschichte der Trigonometrie,* op. cit., vol. 1, p. 126; F. Sezgin, op. cit., vol. 5, p. 56.

[450] A. P. Juschkewitsch and B. A. Rosenfeld, *Die Mathematik der Länder des Ostens im Mittelalter,* op. cit., p. 151; F. Sezgin, op. cit., vol. 5, p. 60.

[451] *Astronomie,* in: Enzyklopaedie des Islām, Bd. 1, Leiden and Leipzig 1913, column 519b.

[452] v. C. Doris Hellman, *Brahe*, in: Dictionary of Scientific Biography, vol. 2, New York 1970, pp. 409-410; F. Sezgin, op. cit., vol. 6, p. 38.

[453] C. A. Nallino, op. cit., column 520a; R. Wolf, *Geschichte der Astronomie*, Munich 1877, pp. 54-55.

by Kepler.[454] Kepler also showed great interest in az-Zarqālī's value of the Sun's apogee, the point of the Sun's greatest distance from Earth (supra p. 34). Copernicus also knew of the model of the Sun developed by az-Zarqālī. He described it as "a nice invention" and used it in his own theory.[455]

The dependence of European scholars on the accomplishments of the Arabic-Islamic area, still discernable in the second half of the 16th century, is not limited to astronomy, but is true of almost all fields of science. For instance, the Europeans' acquaintance with anthropogeography, which had been cultivated in the Arabic-Islamic world and which was already at its peak in the 4th/10th century, commenced rather late. It came about in the first half of the 16th century through the description of Africa known by the name of Leo Africanus, which we have mentioned above (p. 77). The anthropogeographical contents of Idrīsī's *Geography* did not appeal to Europeans until late. Leaving aside the after-effects through its maps that could already be discerned in the 13th century, the *Geography* itself became known through the Latin translation of an extract in 1619. Nonetheless we can follow the impact of al-Idrīsī and Leo Africanus up to the 19th century. In mathematical geography and cartography also, a strong European dependence on Arabic-Islamic predecessors was noticeable until the end of the 18th century and beyond. However, in the 16th century in which creativity began to make itself felt in many fields, anti-Arabism continued to show itself along with Arabism. Now it took the form of a denial of the past and of an immoderate vilification of the Arabs and even the Greeks. Thus Paracelsus (ca. 1493-1541) writes: "There is no need for the fatherland to emulate the thoughts and customs of the Arabs or the Greeks, [167] on the contrary, that would be an error and strange presumption."[456] Agrippa of Nettesheim (1486-1535) is more specific: "Afterwards many barbarian philosophers arose and wrote about medicine for which the Arabs have become so famous that one has taken them for the inventors of the art; and they could easily have claimed that, had they not used so many Latin and Greek names and words and had they not thus betrayed themselves. Therefore the books by Avicenna, Rhazis and Averroes have been invested with the same authority as those of Hippocrates and Galen, and they have received so much credit that whosoever attempts to cure without them, it could have been easily said about him that he ruined the common weal."[457] There was no dearth of defenders of Arabism against such attacks. One of the main defenders of those days was Andreas Alpagus (d. ca. 1520) who, after a stay of about 30 years in Arabic countries, returned to Padua, where he was active as an Arabist, correcting older Latin translations and translating further books from the Arabic, among them the important commentary by Ibn an-Nafīs (d. 687/1288) on the anatomy of Ibn Sīnā. The discovery of the minor blood circulation by Ibn an-Nafīs that is documented in this work found, through the translation, entry into the work of the Spanish physician Miguel Servet (1553) because of which Servet was long considered by the European physicians as the discoverer of minor blood circulation (supra p. 50).

Neither the rejection nor the defense of Arabic-Islamic sciences came to an end with the close of the 16th century, but both continue till today. Islamic culture has on its side no less a person than Johann Wolfgang von Goethe who expressed his admiration explicitly: "If we want to participate in these creations of the most excellent minds, then we must orientalise ourselves, the Orient will not come over to us. And alt-

[454] v. F. Sezgin, op. cit., vol. 6, p. 44.

[455] v. G. J. Toomer, *The solar theory of* az-Zarqāl. *A history of errors*, in: Centaurus (Copenhagen) 14/1969/306-336, esp. p. 310; F. Sezgin, op. cit., vol. 6, pp. 43-44.

[456] v. H. Schipperges, *Ideologie und Historiographie des Arabismus*, op. cit., p. 23

[457] Ibid.

hough translations are highly laudable to entice us, to introduce us, still it is evident from all that has been said before that in this literature, language as language plays the leading role. Who would not want to acquaint himself with these treasures at the source !"[458]

[458] *West-östlicher Divan. Noten und Abhandlungen zu besserem Verständnis des West-östlichen Divans*, in: *Goethes Werke*. Published on behalf of the Goethe- and Schiller Archives by A. Kippenberg, J. Petersen and H. Wahl, Mainz 1932, pp. 234-235; H. Schipperges, *Die Assimilation der arabischen Medizin*, op. cit., p. 165.

III

THE BEGINNING OF STAGNATION AND THE REASONS FOR THE END OF CREATIVITY

[168] In the two preceding chapters I have tried to draw a provisional picture of the role of the Islamic culture and how it unexpectedly entered the stage of world history in the early 7th century AD and quickly reached the threshold of its own creativity on the basis of resolute and intensive reception of the sciences of the preceding and neighboring cultures—a reception that was supported by the state and not disturbed but promoted by religion. Knowledge, procedures, theories and instruments inherited or taken over from other cultures were not only used and developed further but enlarged enormously and brought to a significant culmination through inventions and creation of new areas of knowledge. Yet one also has to take note of the historical reality that around the middle of the 16th century creativity began to slacken and, leaving aside a few exceptions, came to a standstill around the turn of the 16th to the 17th century.

The characteristic features of scholarship in the Arabic-Islamic world included a clear concept of a law of evolution in the area of sciences, the custom of not hiding sources but citing them with almost scrupulous precision, an ethic of fair criticism, the use of experiment as a systematically employed tool in investigation, the formulation and enlargement of scientific terminologies, attention to the principle of balance between theory and practice, and astronomical observations over many years with the help of the observatories built during Islamic times. With the foundation of universities these characteristic features and principles found their most eminent places for cultivation.

The second of the preceding chapters outlined basic features of the phenomenon of reception and assimilation of Arabic-Islamic sciences and of the Arabic translations and revisions of Greek works that took place in the Occident outside Muslim Spain. The process began, as far as we know, in the second half of the 10th century and lasted some 500 years. The beginning of the creative phase in Europe seems to lie in the early 16th century; then, after about another century, Europe assumed the leading role in the history of sciences.

Not infrequently an interested layman who has found out through reading or from hearsay about the achievements of the Arabic-Islamic culture asks an Arabist or an historian of science about the reasons for the noted stagnation of this culture. The question is worded in different ways and can run like this: If the Muslims were so advanced in the history of science, why are they so far behind now?

To answer this question a symposium was held in Bordeaux[1] in 1956 and **[169]** a seminar in Frankfurt[2] in the same year with the main emphasis on the same question. The phenomenon that interests us here was discussed in both events by many Arabists and historians of science under terms like “déclin culturel”, “décadence”, “ankylose”, “Kulturverfall” or “Kulturzerfall”.

[1] *Classicisme et déclin culturel dans l’histoire de l’Islam.* Actes du symposium international d’histoire de la civilisation musulmane (Bordeaux 25-29 Juin 1956), organisé par R. Brunschvig et G. E. von Grunebaum, Paris 1957.

[2] *Klassizismus und Kulturverfall*. Vorträge, ed. by G. E. von Grunebaum and Willy Hartner, Frankfurt 1960.

They are interesting contributions with original ideas from the representatives of various disciplines, searching in their respective field of specialisation for the reasons of the “décadence” or the “decay”, attempting to explain it with due caution and discretion. That so many and widely diverging explanations were brought forward can plunge the reader, particularly a layman, into deep confusion.

Yet we must consider that roughly fifty years ago the conditions for the discussion of this theme were considerably more unfavorable than they are today. Leaving aside the fact that the significance of Arabic-Islamic sciences had not nearly been sufficiently clarified on the basis of individual research, those scholars lacked certain overviews and general descriptions that we have at our disposal today. Within the limited framework of the present treatment of the theme, we do not wish to discuss the explanations and attempts at explanation in those contributions. We may single out just one remark by Willy Hartner,[3] the only historian of science among the participants of the discussion.

Having “outlined the essential stages of the upswing and the decline,” Hartner says: “George Sarton often spoke of the ‘wonder of Arabic culture’ and with this word pointed to the difficulty or even the impossibility of showing the reasons for its upswing. In fact I also do not know an obvious answer to this question.”

By contrast to this understandable caution, I take the liberty of enumerating the factors that can have been involved in the matter, of which I have become aware during my pursuit of the history of Arabic-Islamic sciences.

1. In early Islam the Arabs were obviously in a mood of awakening and confident of victory, and parallel to this they were full of intellectual curiosity and had a thirst for knowledge and were receptive.

2. The new religion, reflecting this spirit, did not hinder sciences, but promoted them.

3. Umaiyad, Abbasid and other statesmen supported sciences in many ways.

4. The cultural representatives of other religions, after the conquest of their homelands by the Muslims, were treated properly, respected and made partners of the new society.

5. Already from the first century onwards there developed in Islamic society a special, fruitful teacher-disciple relationship unknown to the Occident in the Middle Ages and beyond. The pupils did not study from books only, but under direct instruction from the teacher. This facilitated the process of learning and assured reliable knowledge.

6. Natural sciences and philosophy, philology and literature were cultivated and pursued from the outset in a secular manner and not for theological purposes. The pursuit of sciences was not the privilege of the clergy but was open to all professions. Thus in the bio-bibliographical literature the surnames of most of the scientists of the Arabic-Islamic area are designations of professions like tailor, baker, joiner, smith, camel-driver or watchmaker.

7. As early as in the 1st/7th century a system of public instruction began in the mosques. In the 2nd/8th century [170] eminent philologists, men of letters and historians had their own professorial chairs (called *usṭuwāna* “pillar”) in the main mosques. The reports that have come down to us about the methods and manners of lectures and discussions testify to the high academic style of these teaching institutions. These mosques developed spontaneously into the first universities until state universities were founded in the 5th/11th century.

8. The character of the Arabic script permitted easy and fast writing and because of that made possible a wide dissemination of books.

9. A philology that developed fast and thoroughly provided the scholars with a solid base

[3] *Quand et comment s‘est arrêté l‘essor de la culture scientifique dans l‘Islam*?, in: Classisisme et déclin culturel dans l‘histoire de l‘Islam, op. cit., pp. 319-337, esp. p. 328.

for writing their treatises and acquaintance with foreign languages.

10. The acceptance and appropriation of foreign terminology sharpened the insights into exact definitions and scientific precision and led to the creation of specific Arabic technical terminology.

11. The written tradition found the support of the traditional papyrus industry that had already been expanded in the first century of the Higra, and later on through the foundation of factories for the manufacture of paper as writing material that had been adapted from the Chinese and had found enormous circulation in the Islamic world (infra p. 175 ff).[4]

12. It was also very useful that a better and longer lasting ink was developed in the 4th/10th century from an admixture of ink made of iron-gallic (gall-nuts, vitriol, gum Arabic and water) with soot, which made possible a deep-black script that was non-fading and durable, without becoming pale or brown over the course of time.[5]

With full justification we can maintain that all these factors contributed to a fast, broad and thorough development of the sciences in Arabic-Islamic culture and remained effective not only for a short span of time but for centuries. It is unfair to speak frequently of religion in general or of orthodoxy, theology or mysticism in particular as having had an detrimental impact on science. Such reflections do not take into account the fact that the well-known initial upsurge in the development of Arabic-Islamic sciences continued for centuries without interruption and that the creativity did not slacken until the 16th century.

On the contrary, it should be pointed out that one did not have to fear any reaction from theology when calling Aristotle for centuries the "first master" (*al-muʿallim al-auwal*)); and often it was the custom to add the honorific "distinguished" (*al-fāḍil*) while mentioning the names of the great Greek scholars like Archimedes, Galen or Apollonius. But that did not mean that this respect prevented anybody from criticising their Greek teachers. That did happen indeed, only one had a certain ethic of criticism: not to be unfair, exorbitant or arbitrary. Three examples may serve to clarify this:

The first example deals with the three Mūsā brothers (Banū Mūsā, 1st half of the 3rd/9th c.). They improved the book by Apollonius of Pergae on conic sections in some passages and furnished it with proofs, postulates and theorems. Some **[171]** 150 years later the great mathematician and astronomer Abū Naṣr b. ʿIrāq defended Apollonius with the remark that the Banū Mūsā had been wrong in a few cases.[6]

As a second example, we may cite the criticism which Ibn al-Haiṯam levels at Ptolemy by accusing him of having consciously made allowances for errors in order to save his planetary models which he had recognised as false: "These passages we have cited are those with obvious contradictions which we have found in the *Almagest*. Among them are some that are excusable but also such that cannot be excused. It has to do, on the one hand, with oversights which can happen to anybody and which are excusable, but then there are passages in which he committed mistakes knowingly, as in the case of the models of the five planets, and those are inexcusable."[7]

[4] This view is opposed by a tendency noticeable in recent years among some scholars who study Arabic as a secondary subject and hold the Arabic-Islamic culture in certain contempt; they are of the opinion that the Arabs had to import their paper from Italy. For, the Arabs are not generally credited with creativity in the history of science and it is believed that one cannot ascribe to them any influence in the scientific upswing in Europe.

[5] I owe this information to Dr. Armin Schoppen, the author of: *Tinten und Tuschen des arabisch-islamischen Mittelalters. Dokumentation – Analyse – Rekonstruktion*, Göttingen 2006.

[6] v. F. Sezgin, op. cit., vol. 6, p. 137

[7] Ibn al-Haiṯam, *aš-Šukūk ʿalā Baṭlamiyūs*, Cairo 1971, p. 4; F. Sezgin, op. cit., vol. 6, p. 86.

As a third example, we may mention the attitude of the above (p. 35) mentioned mathematician Ibn aṣ-Ṣalāh who followed up almost systematically the criticism of the Greek scholars by his Arabic predecessors, testing its justification and not infrequently defending the former against their critics.

It is indeed conceivable that a reader who is well versed in Arabic literature remembers at this point the work by Abū Ḥāmid al-Ġazzālī (d. 505/1111) entitled *Tahāfut al-falāsifa* in which he refutes some of the views of Greek and Arab philosophers, including those of al-Fārābī and Ibn Sīnā. These refutations reveal the scepticism that an orthodox theologian acquired after a thorough study of philosophy. Even though al-Ġazzālī reacted strongly in the matter, he avoided abuse; moreover, this was above all an individual reaction and not an institutional one. Official opposition and condemnation like that of Averroes at the university of Paris[8] or the Aristotle-prohibition by Pope Innocence III in 1209[9] would have been inconceivable in the Islamic world.

Perhaps it is not superfluous to point out that the freedom and esteem which the Christian and Jewish scholars enjoyed under the Umaiyads and the early ʿAbbāsids and their participation in the scientific upswing continued uninterrupted in later centuries as well. Moreover, they could assume important functions in the state and move freely from Persia to Andalusia and could practise their profession wherever they wished, leaving aside a short period of intolerance under the Almohads in Cordoba. The personal physician of the ruler al-Malik an-Nāṣir Ṣalāḥaddīn (Saladin) and of his son al-Malik al-Afḍal was the famous Jewish physician and philosopher Ibn Maimūn (Maimonides, d. 601/1204).[10] From the middle of the 6th/12th century it is reported[11] that in Baghdad there were three great physicians called Hibatallāh: the Christian Hibatallāh b. Ṣāʿid Ibn at-Tilmīḏ, the Jew Abu l-Barakāt Hibatallāh b. Malkā and the Muslim Hibatallāh b. al-Ḥusain al-Iṣfahānī. Among these three, the Christian Hibatallāh, who was the director of the ʿAḍudī hospital and was mayor of the Christian community, was appointed by Caliph al-Mustaḍīʾ (r. 566/1170-575/1180) spokesman of the medical profession and was entrusted[12] with the professional examination of the medical practitioners in Baghdad and its vicinity. For the Arabic-Islamic [172] culture it was not unusual that the Muslim and historian of medicine Ibn Abī Uṣaibiʿa as well as the Christian historian Ibn al-ʿIbrī wrote in the 7th/13th century about these three physicians belonging to different religions without any discrimination and with great appreciation. How important the atmosphere of tolerance prevailing in the Islamic world was for cultural history becomes clear when one reflects that in 1241 in the Occident a Christian could be excommunicated if he let himself be treated by a Jewish physician.[13] The preceding explanations and examples shall serve as support for my conviction that Islam is to be excluded as the main reason for the recession or the end of productive scientific activity in the Arabic-Islamic world. I am convinced that religion can hardly endanger the advance of sciences seriously in a cultural circle once the process of upswing has developed its own dynamics and has made its way under favorable conditions. Christianity was also unable to stop the process of the reception of Arabic-Islamic sciences and its further development in Europe after it had begun. In the present case, it means

[8] H. Schipperges, *Die Assimilation der arabischen Medizin,* op. cit., p. 136.

[9] ibid, pp. 66, 136, 160.

[10] v. Ibn Abī Uṣaibiʿa, *ʿUyūn al-anbāʾ*, vol. 2, p. 117

[11] Ibn al-ʿIbrī, *Taʾrīḫ muḫtaṣar ad-duwal*, op. cit., pp. 363-364.

[12] v. Max Meyerhof, *Ibn al-Tilmīdh*, in: Encyclopaedia of Islam, New Edition, vol. 3, Leiden and London 1979, pp. 956-957

[13] v. H. Schipperges, *Die Assimilation der arabischen Medizin*, op. cit., p. 128

that we have to identify the real conditions and events that were detrimental.

Above all one has to keep in mind that the Arabic-Islamic sciences began reaching Europe from Arabic Spain from the second half of the 10th century through translations and through technical instruments and devices. About a hundred years later a second path to Europe opened up via Sicily and southern Italy. Then it became of fundamental importance that the Europeans decided to fight against the Islamic world, shortly before the end of the 11th century. The eight wars known under the name of the Crusades lasted from 1095 to 1291. In these military expeditions, which ended once with victory, another time with defeat, the Europeans were in reality always the winners and the beneficiaries. The wars weakened the Islamic world not only in its economy but hindered the process of the scientific development and, through the occupation of parts of Palestine—like a wedge in the centre of the Islamic world—disturbed the circulation of new achievements and of books.

According to the level of our knowledge, the Muslims of those times were far superior to the occupiers in technical knowledge as well as sciences. The occupiers had hardly anything equivalent to contribute. The Muslims, urged on by the spirit of defence, seem to have made noteworthy advances, above all, in the development of weapons such as the windlass crossbow and the counterweight catapult, canons, hand grenades and hand firearms as well as the in use of steel stirrups. But, in the long run, the countries of the crusaders profited more from this progress in the technology of weapons than the inventors themselves. All these new inventions in weapon technology were to be found again in Europe in a time span of about fifty years. There can hardly be any doubt that the weapons and the knowledge of their use and manufacture could reach Europe so quickly mainly through the crusaders.

At the same time when a central area of the Islamic world was suffering under war and occupation by the crusaders, the invasion of the eastern parts by the Mongols began in 613/1216. During the approximately seven years of attacks by the Mongols on Persia that ended in 628/1231 with the conquest of most of the country, many native places of culture and centres of the sciences were devastated. [173] The central part of the Islamic world experienced further destruction in 656/1258 through the conquest of Baghdad by Hülegü, the grandson of Čengīz Ḫān, and through the subsequent conquest of large parts of Syria.

With the conquest of Constantinople (857/1453), the Ottomans had taken over the leadership in the largest part of the Islamic world. With all their ventures of expansion they did not neglect to look after education and science in their empire, and there was no lack of scientific creativity there until the end of the 16th century. Yet the Ottomans were fighting a losing battle, in view of the new situation brought about by the Portuguese and the Spaniards. Of devastating consequence for the leading role of the Muslims in world politics and in the sciences was the loss of Portugal and a significant part of Spain with Toledo in the second half of the 11th century. Thereafter their political presence in the west of the Islamic world diminished progressively until the fall of Granada in 897/1492. After this final loss, the Iberian peninsula with its centres of sciences where Muslims had done important work for centuries was no more counted as a part of the Islamic world, but rather belonged to the Occident. But it should be noted that it was once again Spain and Portugal which—after belonging for a long time to the Arabic-Islamic area—assumed the political as well as scientific leadership on the world stage, before they had to yield place to other western and central European countries at the beginning of the 17th century, at a time when there was also a shift of power in the Arabic-Islamic world.

One should also consider the world-wide political and economic consequences of the discovery of America which could be accomplished by

the Spaniards only thanks to the nautical, technical, astronomical and geographical knowledge that they had appropriated over centuries from the Arabs. That the Spaniards came to discover the fourth continent towards the end of the 15th century should be understood in the sense of the continuity of Arabic-Islamic sciences in Europe. This continuity thus reaped its first fruits under the newly given conditions. With a clear idea of the spherical shape of the Earth and of its size, the Arabs undertook daring voyages even before 1050 AD while they ruled in Portugal, in order to reach Asia, which they knew well, from the western coast of Europe across the great "encompassing ocean". The ventures must have been repeated so often that one street in the harbour of Lisbon was called *Darb al-maġrūrīn* ("street of those who go astray").[14] We do not know whether anybody reached their goal in such an early period when no compass was available for the purpose of navigation, or none that was adequately developed; but the Spaniards, having made themselves politically independent of their Arab predecessors, felt in a position to do so. Although they did not know al-Bīrūnī's (d. 440/1048) indication that the ocean that encircles the inhabited continent might perhaps separate this from a continent that lies further beyond or from an inhabited island,[15] such Christopher Columbus had at his disposal compasses as the Arabic navigators had developed in the Indian Ocean.[16] Even more than this factor, there were two further elements that encouraged Christopher Columbus and made easier his decision to reach India not by the south African route but from the west. The one element was that he adhered to the values of the Arab measurement of the Earth with 56 2/3 miles for one degree, though believing however [174] that the Arabic mile and the Italian mile were the same and both amounted to 1525 km. Accordingly his notion of the circumference of the Earth was too small by about one-fourth.[17] The second encouraging element was the bizarre idea of a pear-shaped Earth through which the path to India from the west would also be made particularly shorter. This incorrect notion was already pointed out in the first half of the 19th century by the famous natural scientist Alexander von Humboldt. The discovery of America was an epoch-making geographical and nautical success that would have been unthinkable but for the long presence of the Muslims on the Iberian peninsula, and inconceivable without the navigation developed by them and the enlarged geographical knowledge, as was already stated by Joseph-Toussaint Reinaud[18] a century and a half ago.

With Granada, the Arabs lost in 1492 not only the last bastion of their 800 years' rule of the Iberian peninsula, the loss marked at the same time the beginning of the final end of the Arabic-Islamic world power. Of course the Ottomans were politically in a position to extend their rule over large parts of the Mediterranean, the Balkans, the area around the Black Sea with the Ukraine and the Caucasus and over the Arab countries up to the Arabian peninsula and northern Africa. The Ṣafavids were still a respectable political power in Persia in the 16th century, and the Islamic Moghul Empire established in India in 1526 possessed even more significant political

[14] v. al-Idrīsī, *Nuzhat al-muštāq*, op. cit., vol. 1, p. 548; J. Klaproth, *Über die Schiffahrten der Araber in das Atlantische Meer*, in: Asiatisches Magazin (Weimar) 1/1802/101-105 (reprint in Islamic Geography, vo. 237, pp. 47-51); s. noch R. Hennig, *Arabische „Abenteuer" im Atlantischen Ozean*, in: Terrae Incognitae, 2nd ed., Leiden 1950, vol. II, pp. 424-432 (reprint in Islamic Geography, vo. 239, pp. 318-326).

[15] v. al-Bīrūnī, *Taḥqīq mā li-l-Hind*, ed. E. Sachau, London 1887, pp. 96, Engl. translation E. Sachau, *Alberuni's India*, London 1910, vol. 1, p. 196; F. Sezgin, op. cit., vol. 10, p. 128.

[16] v. F. Sezgin, op. cit., vol. 10, p. 253.

[17] ibid, vol. 10, p. 280.

[18] *Géographie d'Aboulféda. Traduite de l'arabe en français.* Tome I: *Introduction générale à la géographie des Orientaux*, Paris 1848, pp. 444-445 (reprint in Islamic Geography, vo. 277); F. Sezgin, op. cit., vol. 11, p. 161.

and economic strength. Moreover, the sciences in these three great Islamic empires were still of a high level. Yet the existing balance of power could not have lasted longer after the Islamic world had lost its central geographic position in the old inhabited quarter of the globe through the discovery of America and the appearance of the Portuguese in the Indian Ocean.

In order to understand fully the reasons for this turning point in history, we must also take into consideration the importance of the expeditions around Africa and into the Indian Ocean by the Portuguese, which too began towards the end of the 15th century. In this context, it is of great significance that of all the Europeans it was the Portuguese, whose country had been under Arab rule for four hundred years, who now assumed the role of pioneers on this route. However, it shows an insufficient knowledge and a lack of appreciation of historical reality when one calls the laudable and successful undertaking of these voyages the "discovery" of the sea-route to India and to the Cape of Good Hope, in the sense of a purely Portuguese *descobrimento*. Herodot already reports about a Phoenecian circumnavigation of Africa on the order of Pharao Necho (ca. 596-594 BC).[19] In Islamic times the circumnavigation of Africa was not only a well known fact but there was also a trade route between south Morocco and China.[20] It is a contradiction of a reality of history of science to consider the Portuguese as the founders of a new kind of navigation that enabled them to circumnavigate Africa and to navigate the Indian Ocean unhindered. Now we know quite well that during Arab rule a regular and active navigation existed between the western coasts of the Iberian peninsula and the northwest coast of Africa, which lasted until the rule of the Almohads [175] (1130-1269).[21] In the tradition of this navigation, with the knowledge of the previously sailed sea routes and with the possession of Arab maps, the Portuguese were the first Europeans to reach India by the sea route, and they played a leading role in the Indian Ocean for about a hundred years, thanks to Arab pilots and to locally available perfect regional maps and general maps with information of distances and thanks to a highly developed navigation.

Of course, the Portuguese were initially inferior to the Arabic-Islamic culture in all fields of science for almost a hundred years, but they gained many victories through their uninterrupted expeditions that were motivated politically, economically and for religious reasons and were militarily well prepared. During their invasions lasting more than half a century—even if they were not always victorious—they destroyed the weak Arabic fleet and the Turkish-Ottoman fleet coming later to the succor of the Arabs, they devastated or conquered the coastal areas of the Red Sea, of Southern Arabia, of the Gulf of Persia, of India and the Malay Archipellago, and transported the natural wealth to Portugal. Since the middle of the 16th century the Portuguese made themselves masters of the Indian Ocean that had been for centuries like a land-locked sea for the Islamic world. With their rule and the rule of other Europeans over this area and with the discovery of America, the political, economic and strategic landscape of the world changed totally to the disadvantage of the Arabic-Islamic world. The new economic and military strength thus acquired did not remain limited to Spain and Portugal only but was of advantage to the other European countries as well so that the balance within Europe changed over the course of time.

With these explanations about the upheavals on the world stage brought about by the Spanish and the Portuguese, I follow the aim of demonstrating in a few concrete examples my ideas for the reasons behind the stagnation of creativity

[19] v. F. Sezgin, op. cit., vol. 11, p. 349.

[20] v. ibid, vol. 11, pp. 384, 389 ff.

[21] v. Christophe Picard, *L'océan Atlantique musulman. De la conquête arabe à l'époque almohade*, Paris 1997; F. Sezgin op. cit., vol. 11, pp. 11-12.

in the Arabic-Islamic world. Here we encounter the oft-repeated historical maxim that a culture that was dominant in sciences in its time has to make way for a successor whom it had encouraged and whom it had provided with the weapons with which it is now defeated.

For the illustration of this historical sequence, I see an instructive example in the history of paper which the Muslims on their part, having adapted it from other cultures, developed further, giving it to the Europeans and importing it later again from them. The research hitherto[22] could trace this development to a large extent. I cite first from Alfred von Kremer's *Culturgeschichte des Orients unter den Chalifen* from 1877[23] which, despite its age, is a masterly exposition that has hardly been surpassed. In the earliest period of the Islamic society, he says, "one wrote on the hide of animals, well prepared or not so well, on parchment or also on leather[24] which originated in the factories of South Arabia and which excelled through smoothness and **[176]** fineness. But soon papyrus came into use, since at the conquest of Egypt the Arabs found there a highly developed industry dating from ancient times in the processing of the papyrus plant into writing material. This industry underwent an upswing through the Arab conquest because, as was noted earlier, the old Mohamedan state and administrative laws did not prescribe any tax on crafts and factories. The main seat of this industry was in the Delta, to be precise, in the small town of Būra, a place on the coast in the district of Damiette.[25] Here the papyrus plant that probably grew in plenty in the nearby Menzaleh Lake, was processed and offered in the market. The Arabs even kept the old name of the plant and called it Fāfīr, while the product manufactured from it was called Ḳirṭās after the Late Greek cárta."[26]

"But in the eastern Roman empire where the Byzantine civil service had become extremely fond of writing, as well as in the Occident, the Saracenic factories of Egypt were the only source of supply; consequently there was an extremely brisk export of papyrus to Byzantium for which the price had to be paid in ready money.[27] However, it seems that another type of preparation of paper from other materials was invented in Egypt quite early; otherwise it would be difficult to explain the statement by an old writer to the effect that Caliph Moʿtaṣim who, in his newly built residence in Sāmarrā, settled artisans from all parts of the empire, also let manufactory workers of paper (*ḳirṭās*) come from Egypt to Sāmarrā.[28] But the papyrus plant is totally absent there; consequently the production of paper could only have taken place from other materials: from cotton or linen. The Arabs learned the use of the latter material for the preparation of paper only later; consequently there remains hardly any other explanation possible than to assume that in the Egyptian factories, with the cultivation of cotton propagated by the Arabs, one began gradually to adulterate true papyrus with cotton, by which process one finally came to the discovery of manufacturing paper from cotton only …"

[22] For an overview see *Bibliographie der deutschsprachigen Arabistik und Islamkunde von den Anfängen bis 1986 nebst Literatur über die arabischen Länder der Gegenwart,* ed. by Fuat Sezgin, Gesine Degener, Carl Ehrig-Eggert, Norbert Löchter, Eckhard Neubauer, vols. 1-21, Frankfurt 1990-1995, esp. vol. 1, pp. 287-294, vol. 6, pp. 387-389, and the bibliography in Jonathan M. Bloom, *Paper before print. The history and impact of paper in the Islamic world,* New Haven and London 2001, pp. 249-261.

[23] vol. 2, Vienna 1877, pp. 304 ff.

[24] Ibn an-Nadīm, *Fihrist*, op. cit., p. 40.

[25] v. al-Yaʿqūbī, *Kitāb al-Buldān*, Leiden 1892, p. 338; French transl. Gaston Wiet, *Yaʿḳūbī. Les pays*, Cairo 1937, p. 195.

[26] v. Ibn al-Baiṭār, *al-Ǧāmiʿ li-mufradāt al-adwiya wa-l-aġḏiya*, Cairo 1291 H., vol. 1, pp. 86-87 (s. v. *bardî*), vol. 3, p. 155 (*fâfîr*), vol. 4, p. 17 (*ḳirṭâs*).

[27] v. al-Balāḏurī, *Futūḥ al-buldān*, Leiden 1866, p. 240.

[28] v. al-Yaʿqūbī, *Kitāb al-Buldān*, op. cit., p. 264; Gaston Wiet, *Yaʿḳūbī. Les pays,* op. cit., p. 57.

"But in the period from the beginning of the IIIrd to the middle of the IVth century A.H. a great change took place. One began not only to import Chinese paper that was always very expensive, but in northern Arabia (Tihāma) there began a local paper production …"[29]

"At first an enterprising Chinese brought into the farthest north-eastern province of the Caliph's empire the art of preparing paper from linen; and in a book dating from the second half of the IVth century (the *Fihrist* of Ibn an-Nadīm) we already encounter a longer list of different types of paper from linen. In Samarqand this new industry reached its highest bloom and soon this city became rich and flourished through trade, where the export of paper continued to hold an outstanding position. With the rapid upswing of a national literature and the diligent cultivation of scientific studies, leading to an increased consumption of paper, the production and the trade of this article assumed an enormous expansion; paper factories [177] appeared in all places, but it should not remain unnoticed that in the battle between the linen paper of the east and the cotton paper of the west, the victory went to the latter, undoubtedly because one could produce it more cheaply and could thus gain ground against the expensive rival article."

"When the Saracenes gradually conquered from Egypt the entire north African coast, then Spain and finally Sicily, with the cultivation of the papyrus plant which they introduced into Sicily and of the cotton plant which they made native to Spain as well as to Sicily, they also brought with them the paper production that flourished in Sicily as well as in Spain.[30] The factories of Xativa [Šāṭiba] were in the XIIth century of our era widely renowned for the types of paper they made from cotton which were also exported into the Christian countries of the west, while the eastern parts of Europe received their paper—doubtless also cotton paper—from the Levant and perhaps also from Damascus, according to the name Charta Damascena under which it was known."

"In the XIth and XIIth centuries this Saracenic product supplanted the old parchment throughout Europe and in 1224 Emperor Frederick II finds himself called forth to ban, as it were, cotton paper for certain official documents because of its inferior durability, but the question of price made such bans ineffective. Only in the second half of the XIIIth century does linen paper appear in Europe which probably seems to have been produced by adding parts of linen to the cotton paper in order to get cheaper varieties; perhaps also an invention of the Moors since flax cultivation was carried out by them widely."[31]

"… Books on parchment or papyrus were so very expensive that they were accessible only to a small circle; since the Arabs produced an inexpensive writing material and delivered it not only to the markets in the east but also to those in the Christian Occident, science was made accessible to all …"[32]

Subsequent to the paper production that had existed under Arab rule in Sicily, and in continuation of Spanish paper imports in the 12th century, the first attempts were made in the early 13th century in northern Italy at their own paper production; the first results were inferior until the town of Fabriano near Ancona began its own technique which betrayed features of the Arab art of paper making from the area of the east-

[29] Ibn an-Nadīm, *Fihrist*, op. cit., p. 40. Von Kremer adds here that it must have been "obviously nothing else than cotton paper".

[30] al-Idrīsī [*Nuzhat al-muštāq* p. 556], French transl. P. A. Jaubert, Géographie dʿÉdrisi, vol. 2, Paris 1840, p. 37.

[31] "Particularly in the area of Bāǧa in Spain", see Aḥmad b. Muḥammad al-Maqqarī, *Nafḥ aṭ-ṭīb min ġuṣn al-Andalus ar-raṭīb*, vol. 1, Leiden 1855-1860, p. 100; A. von Kremer, *Culturgeschichte des Orients unter den Chalifen*, op. cit., vol. 2, p. 308.

[32] A. von Kremer, op. cit., vol. 2, p. 308; see also Franz Babinger, *Papierhandel und Papierbereitung in der Levante*, in: Wochenblatt für Papierfabrikation (Biberach) 62/1931/1215-1219 (here offprint, p. 12).

ern Mediterranean and which probably had been brought to Italy by the crusaders.[33] The paper industry that developed in the second half of the 13th century in northern Italy could already hold its own in exports towards the end of the century, rid itself of the Spanish rivals in the first half of the 14th century and win the Arab markets. In this process the business acumen of the Venetians and Genovese played an important role.[34] Since when the Italian paper—leading the market with its advantageous prices—had reached the high quality [178] that distinguishes the extant Arabic manuscripts, I cannot say at present. When I think of the many books known to me which have reached us on that cheap paper and which are no longer usable, then the extent of the loss becomes understandable that came about because of the paper import into the Islamic world.

In order to come to the root of the matter I would like to add an observation that I have made in the course of my pursuit of the history of Arabic-Islamic sciences and their reception and assimilation in the Occident: namely, that in the practical part of technology Europe displayed a remarkably faster ability for reception, dissemination and further development of the received items than in the theoretical sphere.

This may be demonstrated in the case of the reception of the above (p. 20) mentioned astronomical instrument which was called an equatorium in the Latin world. As already mentioned, it was invented in the second half of the 4th/10th century by the astronomer and mathematician Abū Ǧaʿfar al-Ḫāzin. After the prototypes constructed by Arab astronomers in Andalusia, it was, according to my knowledge, introduced outside Spain for the first time in 1276 and 1277 through Campanus of Novara. From then on until the middle of the 16th century, many variations were in circulation which were not always faultless but which demonstrated the preference shown to this instrument in Europe. But what is generally striking, in this case as in others, is an exaggerated tendency towards ornamentation, embellishment and not infrequently unnecessary additions that made the instruments heavy and unwieldy. Moreover, the Europeans did not always reach the level of their Arab predecessors in the rudiments of mathematics, and seldom surpassed them. Yet, the circle of those that were interested grew steadily and the interest fostered the creativity. Thus the Europeans reached and surpassed the Islamic world in the technical field earlier than in the theoretical field. With this is connected the next observation, namely that the Europeans stood less in awe of perspective drawing and were more adept at it than the Muslims. Thus they made possible a wider dissemination of manuscripts with technical contents than the Muslims. The advantage on the part of the Europeans became greater through the development of printing in the middle of the 15th century. The possibility of multiple reproductions of technical drawings in printed material also ultimately benefited mechanical engineering and industrial development. Let us consider the effectiveness that the imaginative drawings of Leonardo da Vinci, Georgius Agricola, Agostino Ramelli and others—their connections to Arab sources seem to be unmistakable—could command because of their wide dissemination through printing, while in the Islamic world in the manuscripts of technical books the drawings were often left out in the expectation that a suitable draughtsman would add them later on. Possibly an earlier introduction of printing could have arrested for some time the slackening creativity in the Islamic world.

[33] v. J. M. Bloom, *Paper before print*, op. cit., pp. 210-211.

[34] v. ibid, p. 212; see also Jean Irigoin, *Les origines de la fabrication du papier en Italie*, in: Papiergeschichte. Zeitschrift der Forschungsstelle Papiergeschichte (Mainz) 13/1963, 5-6/62-67; idem, *Papiers orientaux et papiers occidentaux*, in: *La paléographie grecque et byzantine*, ed. J. Bompaire and J. Irigoin Paris: CNRS 1977, pp. 45-54.

Be that as it may, we must consider the phenomenon from the point of view of the destiny of the great cultures and civilizations which, when the time comes, must give up their position to the successor whose rise they themselves have prepared. However, it happens not infrequently that an historian, in his attempt to find reasons for this phenomenon, mixes up the causes with accidental events. According to our attempt to find reasons, the economical and political weakness of the Islamic world, brought about by an interplay of wars and the "discovery" of new sea routes, seems to have been the main reason for its stagnation in the sciences. **[179]** This view is probably not contrary to truth: that the sciences lost their vigour where they flowed freely for some 800 years, and that they could continue to be effective in the Occident to which they had found their way about 500 years earlier and where the climatic and economic conditions for a continuation of creativity were more favorable. In this youngest culture, the radius of which becomes continuously wider, the science inherited from the predecessors develops with great rapidity. In this situation the task of the historian of science is particularly difficult to keep alive the memory of the importance of the past on the one hand, and on the other to revise and correct the prevalent mode of presentation of the historical development that does not do justice to the factual position.

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Science and Technology
in Islam

II

SCIENCE AND TECHNOLOGY IN ISLAM

VOLUME II

Catalogue of the collection of instruments of the Institute for the History of Arabic and Islamic sciences

by

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in collaboration with

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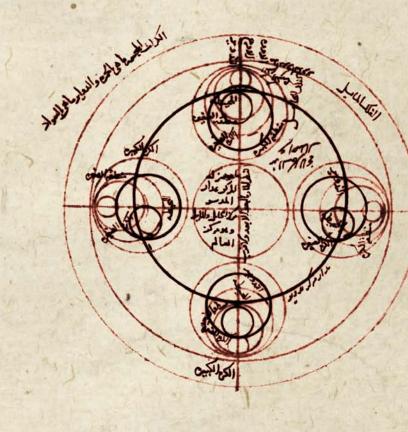
1. ASTRONOMY

2010

Institut für Geschichte der Arabisch-Islamischen Wissenschaften

an der Johann Wolfgang Goethe-Universität

Frankfurt am Main

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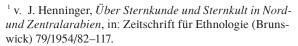
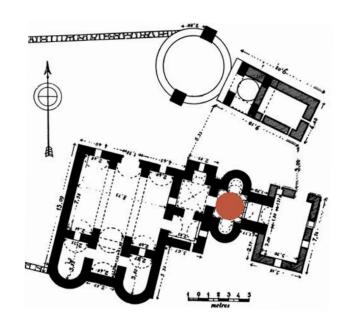
Chapter 1
Astronomy

The whole universe obeys a strict order,
howsoever variable its affairs might be,
and there is harmony between all its parts,
howsoever different they happen to be.

Ibn al-Haiṯam (d. 432/1041)
(From: *Maqāla fī Kaifīyat ar-raṣad*)

[**3**] Introduction

Astronomy, in Arabic *ʿilm al-haiʾa* or *ʿilm al-falak*, is one of the mathematical sciences (*al-ʿulūm ar-riyāḍīya*) and is distinguished from astrology, *ʿilm aḥkām an-nuǧūm* or *ṣināʿat aḥkām an-nuǧūm* (science or art of the laws of the stars). Before the advent of Islam, the Arabs possessed no scientific astronomy, but they did have a rich knowledge of the stars.[1] This knowledge is generally thought to be an offshoot of the Chaldean astronomy.[2] More than 300 stars are mentioned by name in old Arabic and early Islamic-Arabic poetry.[3] Hommel's view that some of the names go back to the Akkadian and Sumerian[4] seems to be correct. It also seems to be certain that the Arabs knew the signs of the zodiac in the 1st/7th century,[5] although it cannot be ruled out that this knowledge goes back to times prior to Islam.
Noteworthy in this connection is the caldarium in the bath wing of the small castle Quṣair ʿAmra[6] (east of ʿAmmān in today's Jordan), in the dome of which the fresco of a celestial atlas is preserved. Alois Musil dealt with the Umaiyad palace from the time of 711-715 in his essays and monographs from 1902, and Fritz Saxl and Arthur Beer[7] pointed out the importance of this star chart for the history of astronomy. It contains some 400 stars, constellations and signs of the zodiac with their celestial coordinates. Without going into the question of the prototype or the source of this representation, we may state that the artists had created a map of the heavens whose meaning [**4**] they had to explain, if need be, to their patron, an Umaiyad prince.[8]

View of Quṣair ʿAmra from the South (photo: K.O. Franke).

Plan of Quṣair ʿAmra (from: Encyclopaedia of Islam, New Edition, vol. 1, p. 612); the caldarium is marked.

[1] v. J. Henninger, *Über Sternkunde und Sternkult in Nord- und Zentralarabien*, in: Zeitschrift für Ethnologie (Brunswick) 79/1954/82–117.
[2] Fr. Hommel, *Über den Ursprung und das Alter der arabischen Sternnamen und insbesondere der Mondstationen*, in: Zeitschrift der Deutschen Morgenländischen Gesellschaft (Leipzig) 45/1891/592–619 (reprint in: Islamic Mathematics and Astronomy vol. 72, Frankfurt 1998, p. 8–35); F. Sezgin, *Geschichte des arabischen Schrifttums* vol. 6, p. 8.
[3] P. Kunitzsch, *Untersuchungen zur Sternnomenklatur der Araber*, Wiesbaden 1961, p. 30; F. Sezgin, op. cit., vol. 6, p. 9.
[4] Fr. Hommel, op. cit., p. 599 (reprint, op. cit., p. 15); F. Sezgin, op. cit., vol. 6, p. 9.
[5] Cf. C.A. Nallino, *ʿIlm al-falak*, Rome 1911, p. 110–111; P. Kunitzsch, op. cit., p. 21; F. Sezgin, op. cit., vol. 6, p. 9–10.
[6] v. Alois Musil, *Ḳuṣejr ʿAmra*. Mit einem Vorwort von David Heinrich Müller. 2 vols., Vienna 1907 (for the reviews, v. *Bibliographie der deutschsprachigen Arabistik und Islamkunde*, vol. 6, Frankfurt 1991, p. 234).
[7] *The Zodiac of Quṣayr ʿAmra* by Fritz Saxl. *The Astronomical Significance of the Zodiac of Quṣayr ʿAmra* by Arthur Beer, in: K.A.C. Creswell, *Early Muslim Architecture*, vol. 1, Oxford 1932, p. 289–303; A. Beer, *Astronomical Dating of Works of Art*, in: Vistas in Astronomy (Oxford) 9/1967/177–223, esp. pp. 177–187.
[8] F. Sezgin, *Geschichte des arabischen Schrifttums,* vol. 6, pp. 11–12.

Reconstruction of the celestial map in the dome of the caldarium of Quṣair ʿAmra (M. Stein).

Photo showing the actual state.

The important evidence of the fact that the representatives of the older cultures already found favourable circumstances in the new cultural circle of becoming active in the scientific sphere in the first century of Islam, includes a report by the universal scholar al-Bīrūnī[9] (d. 440/1048) stating that he knew of an old *Zīǧ* text with astronomical tables on parchment. Here the dates were mentioned according to the Diocletian era (the Coptic calendar). The *Zīǧ* contained, Bīrūnī says, addenda by an anonymous author, among them horoscopes and solar eclipses from the years 90 and 100 of the Hiǧra (710 and 719 AD). The same hand also entered the latitude of the city of Bust as 32°. Al-Bīrūnī thought it advisable to dispel possible doubts about the existence and authenticity of this old book by mentioning the name of its owner. Also through al-Bīrūnī we learn that the Umaiyad prince Ḫālid b. Yazīd, who occupied himself with sciences,[10] had the pseudo-Ptolemaic astrological work καρπός (*Kitāb aṯ-Ṯamara*), which was not lacking in astronomical elements, translated into Arabic[11] before the end of the 1st/7th century. From the point of view of the early encounter of the Muslims with Aristotelian-Ptolemaic notions of the structure and the motion of the universe, it is instructive that the pseudo-Aristotelian tract περὶ κόσμου (*Kitāb al-ʿĀlam*) was already translated into Arabic under the rule of Hišām b. ʿAbdalmalik (ruled 105/724-125/743). From its cosmologica l-geographical and meteorological contents, the Muslims learnt[12] that “the Earth was at the centre of the universe. It moved continuously with the entire heavens, therefore there had to be an axis between two opposite immovable points around which the celestial sphere could turn. The northern of these two poles was always visible as against the southern which was under the Earth. The substance of the sky and of the stars was called ether; it was an element and, unlike the four known ones, was everlasting. The fixed stars revolved together with the entire heavens; ‘in their midst the so-called zodiac is stretched diagonally through the tropics [**5**] as a girdle, divided into parts after the positions of the twelve animals of the circle.’ The number of stars was immeasurable for man. The others, the star planets, were seven in number. They differed from one another in their nature and speed as also in their

[9] *Taḥdīd nihāyāt al-amākin*, Cairo 1962, pp. 267–268; F. Sezgin, op. cit., vol. 6, pp. 13–14.
[10] F. Sezgin, op. cit., vol. 4, pp. 120–126.
[11] v. ibid. vol. 6, p. 15; vol. 7, p. 42.
[12] v. ibid. vol. 6, p. 72; on the German translation v. H. Strohm, *Aristoteles. Meteorologie. Über die Welt*, Berlin 1970, pp. 240–241.

distance to the Earth, and moved in their own orbits that lay inside one another and were surrounded by the sphere of the fixed stars."

In 154/770 the time was already ripe enough for the voluminous *Siddhānta* by Brahmagupta[13] with its complicated content to be translated from Sanskrit into Arabic at the behest of Caliph al-Manṣūr. The time of the translation of the most important works of Indian astronomy may be considered the beginning of scientific astronomy in the Arabic-Islamic world. That it was possible even at such an early period to translate Brahmagupta's *Siddhānta* into Arabic can only be explained by the fact that a kind of reception of the Greek, Indian and late Babylonian sciences had already commenced in Persia under the Sassanids several centuries prior to Islam, and that the translators of the *Siddhānta* were also among the youngest representatives of this eclectic school. They did not merely translate the text; they also began to improve and supplement it, and to compose their own astronomical works.[14]

The rapid development of astronomical knowledge led to the translation of Ptolemy's main works into Arabic. In this process, his book of the "Handy Tables" (πρόχειροι κανόνες) was rendered[15] from a translation that had originated in the Sassanid school.

The familiarity with scientific literature had already advanced so far that in the last quarter of the 2nd/8th century the translation of the complicated and voluminous *Almagest* of Ptolemy could be carried out. This happened on the order of the statesman Yaḥyā b. Ḫālid al-Barmakī (120/738-190/805). To judge the level reached even at that time in the Arabic-Islamic area with regard to astronomy—in fact the sciences in general—it is revealing that the patron was not satisfied with the translation and commissioned others to undertake a second translation.[16]

The present state of research gives the impression that scientific astronomy in the Arabic-Islamic language area was already at the threshold of the period of creativity in the first quarter of the 3rd/9th century, when the reception and assimilation were not yet fully concluded. As indications of this we may mention the following: Caliph al-Maʾmūn assigned to the astronomer Yaḥyā b. Abī Manṣūr[17] (d. between 215/830 and 217/832) the task of verifying the data and observations of Ptolemy's above-mentioned 'Handy Tables'. The results of this undertaking were presented to the Caliph in the work *az-Zīğ al-Maʾmūnī al-mumtaḥan* ("The Maʾmūnian verified Tables").[18] Research showed that Yaḥyā b. Abī Manṣūr used an approximation method, which Ptolemy did not know,[19] for the determination of eclipses. In the works of his contemporary Muḥammad b. Mūsā al-Ḫwārizmī (active mainly at the time of Caliph al-Maʾmūn) indications can also be found for innovations in the field of applied astronomy. As an example, we may mention his procedure for determining the altitude of the pole, i.e. the local latitude, from the altitude of the upper and lower culminations of a circumpolar star.[20] The evidence also includes the fact that, during an expedition by Caliph al-Maʾmūn against Byzantium, the astronomer and mathematician Sind b. ʿAlī[21] employed a new method for the measurement of a degree of the meridian, which he undertook on the ruler's orders. On a coast high above sea level, Sind b. ʿAlī measured the depression of the sun when it was setting and with that calculated trigonometrically the size of the Earth's circumference.[22] (see Fig. next page)

[**6**] Al-Bīrūnī also used this method on a mountain rising high above a plain. Later, the method was connected with the names of Francesco Maurolico (1558), Sylvius Belli (1565) and Francesco Giuntini (d. 1580).[23]

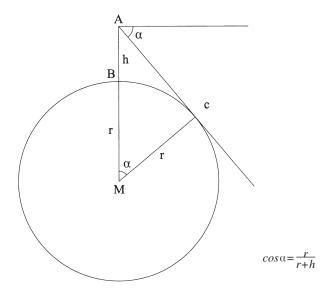
13 F. Sezgin, *Geschichte des arabischen Schrifttums,* vol. 6, pp. 118–120.

14 Ibid., vol. 6, pp. 122–127.

15 Ibid., vol. 5, p. 174; vol. 6, pp. 13, 95–96.

16 Ibid., vol. 6, p. 85.

17 Ibid., vol. 6, p. 136.

18 Facsmile edition of the Institut für Geschichte der Arabisch-Islamischen Wissenschaften, Frankfurt 1986.

19 v. E.S. Kennedy and N. Faris, *The Solar Eclipse Technique of Yaḥyā b. Abī Manṣūr*, in: Journal of the History of Astronomy (London) 1/1970/20–37; F. Sezgin, *Geschichte des arabischen Schrifttums,* vol. 5, p. 227; vol. 6, p. 136.

20 F. Sezgin, *Geschichte des arabischen Schrifttums,* vol. 10, p. 151.

21 Ibid., vol. 6, p. 138.

22 Ibid., vol. 6, p. 138; vol. 10, p. 96.

23 v. S. Günther, *Handbuch der mathematischen Geographie*, Stuttgart 1890, pp. 217–218.

A, α, h, B, c, r, r, α, M

$$\cos\alpha = \frac{r}{r+h}$$

Calculation of the Earth's radius by Sind b. ʿAlī.

We should also mention here the subsequent measurements of the Earth's circumference that were done on Caliph al-Maʾmūn's orders. He repeatedly tried to ascertain the length of a degree of the meridian as accurately as possible. The measurements were taken by several astronomers either in the plains of Sinǧār or between Raqqa and Tadmur (Palmyra). The task was accomplished with instruments for determining the position of the Sun and the line of the meridian, and with the help of staves and ropes. After repeated measurements had produced values between 56 1/3 and 57 miles, it was decided to take the mean value of 56 2/3 as the length of a degree of the meridian. The result differs just minutely from today's accepted value. According to C. A. Nallino, this was the first scientifically achieved measurement, accomplished by an effort that lasted over a long period of time.[24]

From the point of view of the rapid development of astronomical science in the following centuries, it was undoubtedly of great significance that al-Maʾmūn established observatories in Baghdad and also on Mount Qāsiyūn, north of Damascus. [25] These were probably the first regular observatories run by the state.

The attempt to find new astronomical data as exactly as possible and to verify older data characterises the main goal of Arab-Islamic astronomers in the 3rd/9th and 4th/10th centuries. Since they possessed—as compared to their Greek, Indian and Sassanid-Persian predecessors—better methods of computation, better instruments for measuring and observation, and a better technique of observation, they came remarkably close to this goal.[26] If we are to mention some of the relevant results achieved by the astronomers of those days, then we must count the substantially improved value for the precession of the equinoxes[27] at 1° in 66 years, that is to say 55'' in one year, which already appears in Ṯābit b. Qurra's works. Ptolemy, following Hipparchus, had calculated this phenomenon[28] with 1° in one hundred years, which corresponds to 36'' in one year. Later astronomers, beginning with al-Battānī, improved the value. Naṣīraddīn aṭ-Ṭūsī (d. 672/1274) calculated it as 1° in 70 years, i.e. 51'' in one year,[29] a value "which the modern period could almost adapt as its own."[30]

Towards the end of the 3rd/9th century, there arose in the circle of Arabic-Islamic astronomers the view that the Sun's apogee (*auǧ aš-šams*) moves in the direction of the ecliptic (i.e. in the direction of the increasing longitudes of the heavens). Ṯābit ibn Qurra[31](d. 288/901) seems to have been the first to make such an observation. [7] Al-Battānī[32] (d. 317/929) followed him. But only a hundred years later al-Bīrūnī succeeded in giving a precise definition of the extremes of deceleration and acceleration of this motion.[33] In the second half of the 5th/11th century Ibrāhīm b. Yaḥyā az-Zarqālī found

[24] F. Sezgin, *Geschichte des arabischen Schrifttums,* vol. 10, pp. 95–96.

[25] Ibid., vol. 10, p. 116.

[26] Ibid., vol. 6, p. 20.

[27] This has to do with the annual advance of the vernal equinox, which is measured according to its longitudinal distance from Spica. Modern astronomy considers the precession of the equinoxes to be caused by the flattening of the Earth; v. R. Wolf, *Handbuch der Astronomie, ihrer Geschichte und Literatur*, vol. 1, Zurich 1890 (reprint Hildesheim 1973), pp. 440–442.

[28] The question of the earliest knowledge of this phenomenon seems not yet to have been answered definitely; v. Otto Neugebauer, *The alleged Babylonian discovery of the precession of the equinoxes*, in: Journal of the American Oriental Society (Ann Arbor) 70, 1950, pp. 1–8; Peter Huber, *Über dem Nullpunkt der Babylonischen Ekliptik*, in: Centaurus (Copenhagen) 5, 1956–58, pp. 192–208.

[29] F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 6, p. 26.

[30] R. Wolf, *Handbuch der Astronomie*, p. 441.

[31] v. F. Sezgin, vol. 5, pp. 264–272; vol. 6, pp. 163–170, esp. p. 163.

[32] F. Sezgin, *Geschichte des arabischen Schrifttums,* vol. 6, pp. 182-187, esp. p. 184.

[33] Ibid., vol. 6, p. 263.

the value of the forward movement of the apogee to be one degree in 279 years, i.e. 12.09'' in one year, which approximates to the present value.[34]
As a consequence of their continuous observation of the sky, the astronomers of the Islamic world achieved other important results. Ibrāhīm b. Sinān b. Ṯābit (lived between 296/909 and 335/946) was obviously the first person to realise that the obliquity of the ecliptic is not constant. He explained the deviations noticed in the results of his observations in the course of time as a consequence of sudden and irregular movements of the world's axis.[35]
His contemporary Abū Ǧaʿfar al-Ḫāzin reached the same conclusion.[36] Their younger contemporary, Ḥāmid b. al-Ḫiḍr al-Ḫūǧandī, motivated his patron, the Buyid ruler Faḫraddaula (ruled 366/976-387/997), to build an observatory with a sextant with a radius of ca. 20 m in Raiy (in the south of modern Tehran) to obtain a more accurate result on the question of the obliquity of the ecliptic. His observations, made possible through this, led him to the conviction that the obliquity of the ecliptic declines continuously in the course of time.[37]
Even before al-Ḫuǧandī's explanation, the attempt to reconcile the changes in the obliquity of the ecliptic with the precession had led Ṯābit b. Qurra to propound the hypothesis of the trepidation, a forward and backward movement of the fixed stars (*ḥarakat al-iqbāl wa-l-idbār*).[38] This hypothesis proved to be more of a stimulus for astronomers in Europe than for those in the Arabic-Islamic world
As far as the advances made in respect of topics like the total solar eclipse, variability of the Sun's diameter, eccentricity of the Sun's orbit, computation of the parallaxes, as well as the computation of the first visibility of the crescent Moon, I restrict myself to a reference to the relevant pages in the Geschichte des arabischen Schrifttums (vol. 6, pp. 27-28). Only the case of fixed star astronomy may be briefly mentioned here.
As stated already, before the advent of Islam the Arabs possessed quite a good knowledge of the fixed stars. In Islamic times there was at first a remarkable philological comprehension of this subject. Only after the acquaintance with the Ptolemaic *Almagest*, did a preoccupation with fixed star astronomy proper begin. After the work accomplished by the Greek predecessors, this branch of astronomy reached a new climax in the second half of the 4th/10th century in the work of ʿAbdarraḥmān aṣ-Ṣūfī,[39] in particular through his *Kitāb Ṣuwar al-kawākib aṯ-ṯābita*.[40] This eminent astronomer verified the data in the catalogue of Hipparchus-Ptolemy on the basis of his own observations and measurements, and compiled a new catalogue with largely revised scales of brightness, coordinates and magnitudes of stars. A further revision of the star catalogue was made on the basis of fresh observations at the observatory of Uluġ Beg (d. 853/1449) in Samarqand. This new catalogue distinguished itself from its predecessor primarily through more precise coordinates.
ʿAbdarraḥmān aṣ-Ṣūfī, together with Ptolemy and Argelander (d. 1875), is considered to be one of the three great pioneers of fixed star astronomy. For centuries, he deeply influenced the subject not only in the Islamic world but in Europe as well.[41]
The fixed star catalogue in the Alfonsine compendium *Libros del saber de astronomía* (ca. 1277) is nothing but a free Castilian rendering or revision of ʿAbdarraḥmān aṣ-Ṣūfī's work. An Italian translation, prepared after the Castilian version in 1341 [**8**] has been known since 1908.[42]
"In what high esteem Ṣūfī was held in the Occident as late as at the beginning of the modern age can be seen from the fact that Albrecht Dürer mentions him under the name of Azophi as one of the four great representatives of astronomy"[43] (see Fig. next page).

[34] F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 6, pp. 26–27.
[35] Ibid., vol. 6, p. 194.
[36] Ibid., vol. 6, p. 189.
[37] Ibid., vol. 6, pp. 220–222.
[38] Ibid., vol. 6, p. 164.

[39] v. ibid., vol. 6, pp. 212–215.
[40] Facsimile edition of Institut für Geschichte der Arabisch–Islamischen Wissenschaften, Frankfurt 1986.
[41] F. Sezgin, op. cit., vol. 6, p. 212.
[42] v. Oiva J. Tállgren, *Observations sur les manuscrits de l'Astronomie d'Alphonse X le Sage, roi de Castille*, in: Neuphilologische Mitteilungen (Helsinki) 5–6/1908/110–114, esp. p. 110 (reprint in: Islamic Mathematics and Astronomy, vol. 99, pp. 1–5, esp. p. 1).
[43] A. Hauber, *Zur Verbreitung des Astronomen Ṣūfī*, in: Der Islam (Strassburg, Hamburg) 8/1918/48–54, esp. p. 52 (reprint in: Islamic Mathematics and Astronomy, vol. 26, Frankfurt 1997, pp. 326–332, esp. p. 330).

A. Dürer, Celestial map
(detail with aṣ-Ṣūfī), wood-cut (1515)

The remaining names in Dürer's wood-cut of the celestial map of 1515 besides Azophi Arabus are Aratus Cilix, Ptolemeus Aegyptius and M. Manilius Romanus.[44] In connection with fixed star astronomy, we may also mention that the question of whether or not the Milky Way formed part of the fixed stars was clearly decided and discussed by Ibn al-Haiṯam (d. 432/1041).[45]
In general, we may cite here the impression already gained in a relatively early stage of modern research on Arabic-Islamic astronomy by the scholar C. A. Nallino[46] on the great progress made by the Arabic astronomers, as against their predecessors, in the development of observational instruments and new methods: "Lastly, in the application of trigonometrical formulae, in the number and the quality of their instruments, in the technique of their observations the Arabs have splendidly outstripped their predecessors the Greeks. In the number, continuity and precision of the observations we mark the most striking contrast between Greek and Muslim astronomy."
Another set of noteworthy topics were the views and hypotheses of the Arabic-Islamic astronomers on the question of the Earth's rotation and on their planetary theories. The Greek notion that the Earth was formed as a sphere reached them at the latest with the pseudo-Aristotelian tract περὶ κόσμου towards the end of the 1st/7th century and was accepted without any opposition whatever. From it they learnt that the Earth lay at the centre of the universe and that the latter moved continuously together with the entire heavens (above, p. 4). It seems the question of the Earth rotating around itself was discussed again and again from the 3rd/9th century onwards—not only by astronomers but by philosophers as well. But for a meagre statement by Plutarch [47] (d. ca. 120 to 125 AD) in the *Placita philosophorum*, no other impulse seems to have come on this subject from the side of the Greeks. In any case, Aristarchus's[48] view of a heliocentric system does not seem [**9**] to have reached them. On the other hand, they learnt at the latest through al-Bīrūnī about the view of the Indian astronomer Āryabhaṭa (ca. 499 AD) on the Earth's rotation.[49] The geographer Ibn Rustah (last quarter of the 3rd/9th c.) speaks, among other things, about the theory that the Earth is situated in the universe, but not at its centre, and that it rotates, but not the Sun nor the outermost sphere.[50] From al-Bīrūnī we learn the names of two Muslim scholars who advocated the idea of the Earth's rotation. They are Aḥmad b. Muḥammad as-Siǧzī (2nd half of the 4th/10th c.) and Ǧaʿfar b. Muḥammad b. Ǧarīr (4th/10th c.). Starting with this notion, they both are said to have built an astrolabe in the form of a boat.[51]

[44] W. Voss, *Eine Himmelskarte vom Jahre 1503 mit den Wahrzeichen des Wiener Poetenkollegiums als Vorlage Albrecht Dürers*, in: Jahrbuch der preußischen Kunstsammlungen (Berlin) 64/1943/89–150; P. Kunitzsch, *Ṣūfī Latinus*, in: Zeitschrift der Deutschen Morgenländischen Gesellschaft (Wiesbaden) 115/1965/65–74, esp. p. 65.
[45] E. Wiedemann, *Über die Milchstraße bei den Arabern* (Beiträge zur Geschichte der Naturwissenschaften. LXXIV), in: Sitzungsberichte der Physikalisch–medizinischen Sozietät (Erlangen) 58–59/1926–27/348–362, esp. p. 358 (reprint in: Aufsätze vol. 2, Hildesheim 1970, pp. 662–676, esp. p. 672), v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 6, p. 254; cf. P. Kunitzsch, *al-Madjarra*, in: The Encyclopaedia of Islam. New Edition, vol. 5, Leiden 1986, pp. 1024–25.
[46] *Astronomie*, in: Enzyklopaedie des Islām, vol. 1, Leiden and Leipzig 1913, p. 520.
[47] F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 6, pp. 81-83.
[48] Ibid., vol. 6, pp. 74–75.
[49] F. Sezgin, op. cit., vol. 6, pp. 224–225.
[50] *Kitāb al-Aʿlāq an-nafīsa*, ed. M.J. de Goeje, Leiden 1892 (reprint Islamic Geography, vol. 40, Frankfurt 1992), pp. 23–24.
[51] al-Bīrūnī, *at-Taṭrīq ila stiʿmāl funūn al-asṭurlābāt*, Paris

Al-Bīrūnī appears to have seriously tried to reach a satisfactory clarification of this question. He wrote a treatise on this issue entitled "On the Rest or Motion of the Earth" (*Kitāb fī Sukūn al-arḍ au ḥarakatihā*),[52] which is not extant. For a long time he was probably vacillating as to whether or not he should decide for the Earth's rotation, but towards the end of his life he reached the conviction that the Earth, after all, was at rest. In his work on India (written ca. 421/1030) he says: "The rotation of the Earth does in no way harm the results of astronomical science, but the things which belong here are logically connected (even with this assumption) in the same way. There are other reasons which should make this assumption impossible."[53] Ibn al-Haiṯam also deals with the question in his commentary on the *Almagest* and declares himself against the rotation.[54]

It should be noted further that in the first half of the 4th/10th century Abū Ǧaʿfar al-Ḫāzin found a new explanation for the apparent non-uniformity of planetary revolutions, as can be seen from al-Bīrūnī's citations. In the model proposed by him he rejects the theories of eccentricity and epicycles, and replaces them with the assumption of variations of the respective planetary orbits up to the plane of the ecliptic. A similar model is proposed by Heinrich of Langenstein (1325-1397).[55]

In the course of the geometrical representation of the planetary motions in continuation of the work by their Greek predecessors, the Arab astronomers postulated a wealth of theories from the second half of the 4th/10th century onwards which were to bear their most important fruit in the work of Copernicus.

Abū Naṣr b. ʿIrāq, the teacher of al-Bīrūnī (2nd half of the 4th/10th c.), discusses from various aspects the possibility of elliptical planetary orbits with very small difference between the lengths of the two axes and the possibility of the actual non-uniformity of revolutions. As against the view of a colleague, to which he refers here, he himself is convinced of a constant, uniform motion of the planets. The apparent non-uniformity and the variations in the diameter of the planetary orbits, noticed in observations, were to be explained with eccentricity. Obviously he did not consider it necessary to take the help of epicyclical motion.[56]

At the beginning of the 5th/11th century Ibn al-Haiṯam introduces the theory of spheres of the Ptolemaic *Hypotheseis* into Arabic astronomy. Accordingly the mathematical model of the heavenly motion had to be replaced with the concept of tangible hollow spheres. Without doubt this recasting of the traditional presentation of the *Almagest*, which was largely followed until the 16th century both in the Islamic world and in the Occident, was in a way a retrograde step. However, with this attempt by Ibn al-Haiṯam an entirely new explanation of the planetary motions becomes evident. He states this in the following words:

"1. The natural body on its own does not perform more than one single natural motion."

"2. The natural simple body does not perform a motion of variable speed, [**10**] i.e. it always covers the same distances in the orbits during the same periods of time."

"3. The body of the heavens is not susceptible to any influence."

"4. Empty space does not exist." [57]

An important step in the elucidation of the Ptolemaic planetary model was again taken by Ibn al-Haiṯam. In his tract on the doubts about Ptolemy, he is the first to notice that, in his explanation of planetary motion, Ptolemy violates the basic principle of uniform motion by introducing the equant, because after this the motion of the centre of the epicycle in the deferent does not remain uniform any more.[58] As we learn from a quotation, Ibn al-Haiṯam developed his own planetary theory in which he

Bibliothèque nationale, ar. 2498, fol. 9a; F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 6, pp. 224–225.

[52] F. Sezgin, op. cit., vol. 6, p. 275.

[53] A propos de ses raisons, v. Sezgin, op. cit., vol. 6, p. 31; E. Wiedemann, *Zu den Anschauungen der Araber über die Bewegung der Erde*, in: Mitteilungen zur Geschichte der Medizin und der Naturwissenschaften (Leipzig) 8/1909/1–3, esp. p. 2 (reprint in: Gesammelte Schriften, vol. 1, Frankfurt 1984, pp. 287–289, esp. p. 288).

[54] F. Sezgin, op. cit., vol. 6, pp. 31–32.

[55] Ibid., vol. 6, pp. 189–190.

[56] Ibid., vol. 6, pp. 242–243.

[57] *Kitāb Haiʾat al-ʿālam*, after the translation by K. Kohl, *Über den Aufbau der Welt nach Ibn al Haiṯam*, in: Sitzungsberichte der Physikalisch-medizinischen Sozietät (Erlangen) 54–55/1922–23 (1925)/140–179, esp. p. 144 (reprint in: Islamic Mathematics and Astronomy, vol. 58, Frankfurt 1998, pp. 94–133, esp. p. 98); F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 6, p. 33.

[58] v. F. Sezgin, op. cit. vol. 6, p. 34.

enumerates the conditions for the uniform motion of the planets. The context of this introduction does not permit us to trace the lasting influences which resulted from this attempt.

The well-known representatives of the new planetary models of the 7th/13th and the 8th/14th centuries were Naṣīraddīn aṭ-Ṭūsī (d. 672/1274), Quṭbaddīn aš-Šīrāzī (d. 710/1311) and ʿAlī b. Ibrāhīm Ibn aš-Šāṭir (d. ca. 777/1375). Their attempts to free the system of planetary motions from Ptolemaic defects, each through his own kinematic model, reached their climax with the latter scholar. In his models, Ibn aš-Šāṭir removes eccentricity and lets the vector (one for each planet) start from the centre of the universe, while accepting aṭ-Ṭūsī's principle of double circles. Particularly important is his model of Mercury. He also succeeds very well in his attempt to create a better model than his predecessors for lunar motion. While creating the uniform circular motion of the Moon, he corrects Ptolemy's grave mistake by exaggerating the variation of the Moon-Earth distance.[59]

In the 6th/12th century in the western part of the Arabic-Islamic cultural sphere opposition to the Ptolemaic image of the world arose, the arguments of which were more of a philosophical than a kinematic-geometrical nature. The philosopher Ibn Bāǧǧa (Avempace, d. 533/1139) rejected the existence of epicycles and thought that the force of eccentricity would account for all planetary orbits.[60] About half a century after him, Ibn Ṭufail (d. 581/1185) intervened in the discussion and rejected the theory of eccentricity as well as that of epicycles. He believed to have found his own explanation but does not seem to have put it to paper.[61]

His contemporary Muḥammad b. Aḥmad Ibn Rušd (Averroes, d. 595/1198) also rejected the theories of eccentricity and epicycles. According to his view, the planets followed a spiral motion (*ḥaraka laulabīya*).[62]

The youngest representative of the Western school in the Arabic-Islamic world was Nūraddīn al-Biṭrūǧī (d. ca. 600/1204). He too rejected the theories of eccentricity and epicycles, and was of the opinion that the planetary spheres must lie concentrically around the centre of the Earth, and that the planets, as with Ibn Rušd, move in a spiral around different axes. While proposing this, he disavowed the west-east motion of the celestial bodies; it was merely an optical illusion that came about because the planets moved from the east to the west, but much more slowly than the celestial sphere.[63] The work of al-Biṭrūǧī (Alpetragius), after its translation into Hebrew and Latin, "progressively influenced scientific-astronomical thinking" in the Occident from the 7th/13th to the 9th/15th century.[64]

When I now proceed to give an idea of the process of reception and the continuation of astronomy in the Occident in broad outlines, [**11**] I will restrict myself to taking up a few points from what I discussed rather extensively (pp. 37-59) in the sixth volume of my Geschichte des arabischen Schrifttums twenty-five years ago.

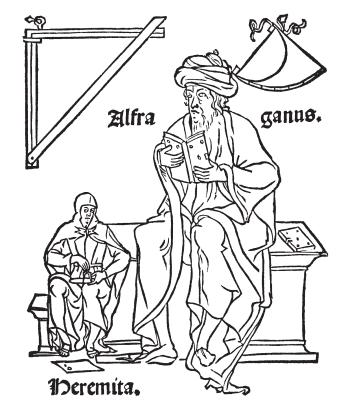
Like the other sciences and the philosophy of the Arabic-Islamic world, astronomy too reached Europe mainly through the paths of Spain, Sicily/Italy and Byzantium, if one leaves aside the knowledge, the books, instruments and also maps that reached the West through human contacts, particularly during the Crusades.

According to the state of our knowledge, the notion may be correct that, at the latest in the 4th/10th century, there existed in the parts of the western Occident bordering on the Arabic-Islamic world, the desire to take over the foreign knowledge through translations, and that conditions had been created for such translations. The earliest translator known by name was Lupitus of Barcelona, who rendered an astronomical treatise into Latin under the title *Liber de astrologia* for Gerbert of Aurillac in the year 984 AD. Likewise from the 10th century a

[59] Ibid., vol. 6, p. 36.

[60] L. Gauthier, *Une réforme du système astronomique de Ptolémée, tentée par les philosophes arabes du XII^e^ siècle*, in: Journal Asiatique (Paris), 10^e^ série, 14/1909/483–510, esp. pp. 497–498 (reprint in: Islamic Mathematics and Astronomy, vol. 63, Frankfurt 1998, pp. 205–232, esp. pp. 219-220); C.A. Nallino, *Astronomie*, in: Enzyklopaedie des Islām, vol. 1, Leiden and Leipzig 1913, p. 520; F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 6, p. 36.

[61] Ibid., vol. 6, p. 36.

[62] Ibid., vol. 6, pp. 36–37.

[63] Ibid., vol. 6, p. 37.

[64] W. Petri, *Tradition und Fortschritt in der Astronomie des Mittelalters*, in: Accademia Nazionale dei Lincei. Convegno Internazionale 9–15 Aprile 1969, Rome 1971, pp. 633–645, esp. p. 642.

compendium of scientific topics is preserved in Barcelona which contains among others tracts on *De mensura astrolabii* and *De utilitatibus astrolabii* and a *Geometria*. There is no doubt that these treatises are free translations or adaptations of Arabic models. The second oldest known author of a tract on the astrolabe in the Occident (*De utilitatibus astrolabii*), Gerbert, obviously used these and perhaps other treatises as his basis. He retains the Arabic technical terms and the form of the Arabic astrolabe. His adaptation of Arabic texts on the astrolabe led to further books on the same subject in the 11th century.

While the city of Toledo (under Muslim rule from 711 to 1085) was the most important centre of reception of Arabic-Islamic sciences in the 10th and the 11th centuries, cities like Chartres, Toulouse, Reims, Tours, Montpellier and Paris became centres of reception and assimilation in the 12th century. From the first half of the 12th century more important and more voluminous works of Arabic astronomy already became accessible in translations.

The handbook of astronomy by al-Battānī, which contains substantial innovations and corrections of Ptolemy's *Almagest*, was translated into Latin by Plato of Tivoli around 1120. Through it for the first time the Ptolemaic image of the world also became known to a large extent among scholars of the Occident. This was followed by the translation of al-Farġānī's (1st half of the 3rd/9th c.) popular handbook of astronomy by Johannes Hispaniensis (Hispalensis) around 1134. The astronomical tables of al-Ḫwārizmī (1st quarter 3rd/9th c.) were translated around 1120-30 by Adelard of Bath.[65]

While the process of reception of Arabic-Islamic astronomy in the Occident was not yet over, towards the middle of the 12th century certain signs can be noticed for the beginning of an assimilation of the newly gained knowledge. The gradual transition from one stage to the other and finally to that of the Occident's own creative activity took around half a millennium from the 10th century. This [**12**] process is made vivid for the reader through the material from Latin and Hebrew translations which P. Duhem compiled and interpreted in the third and other volumes of his work *Le système du monde*.

Al-Farġānī, xylographie extraite de la traduction de Jean Hispalensis, Ferrara 1493.

The course of reception and assimilation received a decisive impulse through the work of Gerard of Cremona, who is said to have translated approximately 70 works from the Arabic in the second half of the 12th century among them many and important astronomical titles.

Gerard's translation of the critique of Ptolemy's *Almagest* by Ǧābir b. Aflaḥ (6th/12th c.) exercised great influence. Especially the trigonometric expositions contained in it influenced Richard of Wallingford (ca. 1292-1336), Simon Bredon (ca. 1300-1372), Regiomontanus (1436-1476) and Copernicus (1473-1543).[66] His translation of the astronomical tables (*Zīǧ*) of az-Zarqālī (5th/11th c.) had a lasting influence on Georg Peurbach (1423-1461), Regiomontanus, Copernicus and Kepler (1571-1630).[67]

Through his edition (*Scripta Marsiliensis super Canones Archazelis*) Wilhelm (William) Anglicus, one of the representatives of Arabic astronomy in Marseilles in the first half of the 13th century, secured a wider dissemination of az-Zarqālī's

[65] F. Sezgin, op. cit., vol. 6, p. 39 s.

[66] F. Sezgin, op. cit., vol. 6, p. 42.

[67] Ibid., vol. 6, pp. 42–44.

Toledan Tables in the Occident. Of special interest is the fact that he attempted, in an elucidation of Ptolemaic astronomy under the title Astrologia, to present the theory of trepidation by Ṯābit b. Qurra and az-Zarqālī as well as al-Biṭrūǧī's system, very clearly differentiated from one another.[68]

At the beginning of the 13th century, this circle of scholars already knew from other translations—besides Ǧābir b. Aflaḥ's critique of the *Almagest*—about the battle fought by the philosophers of the western part of the Islamic world against the Ptolemaic image of the world. Michael Scotus (d. ca. 1235) not only translated al-Biṭrūǧī's work on astronomy, but also Ibn Rušd's commentaries on Aristotle's *Metaphysics* and *De caelo*, where Ibn Rušd spoke against eccentricity and epicycles, and emphasised the necessity of projecting a new world system. With this, the translator Michael Scotus was the first to introduce into the Latin world the basic principles of the anti-Ptolemaic theories of Ibn Rušd and al-Biṭrūǧī. For his contemporaries, it was quite confusing that he put together the expositions of Ibn Rušd and al-Biṭrūǧī in a text under the title *Quaestiones* and circulated them under the authorship of Nicolaus Damascenus (b. 64 B.C.).[69]

Under the influence of Michael Scotus, William of Auvergne (Guillaume d'Auvergne), bishop of Paris (1228-1249), who fought Averroism in the field of theology, also adapted al-Biṭrūǧī's system of the configuration of the world in his *De universo*. In De universo he propounded the view that al-Biṭrūǧī's thesis was suitable to show that the entire heaven was moved according to the principle of a sole mover.[70]

About the middle of the 13th century a fierce dispute between the adherents of Ptolemy and those of al-Biṭrūǧī was already raging. Robert Grosseteste (d. 1253) belongs to the important personalities of the assimilation process of Arabic sciences. That his scholarship must be judged under this aspect was made clear by P. Duhem[71] for the field of astronomy. In his *Compendium sphaerae*, Grosseteste, as the first in the Christian Occident, introduces the principles of Ṯābit b. Qurra's work on the eight spheres, among them the theory of trepidation, and discusses the views of Ptolemy and al-Battānī. He speaks about "al-Biṭrūǧī's discovery" which he also calls "the system of Aristotle and al-Biṭrūǧī". According to Duhem,[72] Grosseteste does not know Aristotle's system of homocentric spheres. He identifies it with that of al-Biṭrūǧī to which alone his exposition refers. Also the treatises *Opuscula and Tractatus de inchoatione formarum*, circulated under his name, clearly show al-Biṭrūǧī's influence.[73] Duhem[74] states that the indecision towards the principles [**13**] of astronomy is shared by Grosseteste and many of his contemporaries: on the one hand he followed the (Arab) adherents of Ptolemy in questions that have to do with the motion of the planets and the preparation of the calendar, and accepted the theories of eccentricity and epicycles; on the other, he let himself be enticed by the simplicity of al-Biṭrūǧī's homocentric spheres.[75]

Albertus Magnus (ca. 1200-1280), one of the most famous Occidental scholars of his century, in his far-reaching scholarship discussed anew al-Biṭrūǧī's system of the world and introduced it to wider circles in a simplified and partly modified form. In his dispute with the Ptolemaic system he is mainly dependent on Arab astronomers, particularly on Ṯābit b. Qurra.[76]

The vacillating attitude of the Dominicans around Albertus Magnus towards a decision for or against one of the two systems also applies to a large extent to the Franciscans around Roger Bacon (ca. 1219-1292). As Duhem[77] saw quite rightly, Bacon attempted throughout his life to reach a decision about the one system or the other, but he remained forever undecided. He knew the astronomy of al-Farġānī and al-Battānī rather well, preferred Ṯābit's value of the precession to that of Hipparchus and Ptolemy, accepted Ibn al-Haiṯam's concept of solid spheres, and considered on the antagonistic side not only al-Biṭrūǧī but also Ibn

[68] v. P. Duhem, *Le système du monde. Histoire des doctrines cosmologiques de Platon à Copernic*. Nouveau tirage, vol. 3, Paris 1958, pp. 287–291.

[69] v. ibid., vol. 3, pp. 241–248; F. Sezgin, op. cit. vol. 6, pp. 45–46.

[70] P. Duhem, *Le système du monde*, vol. 3, pp. 249–260; F. Sezgin, op. cit., vol. 6, p. 46.

[71] *Le système du monde*, vol. 3, pp. 277–287.

[72] Ibid., vol. 3, p. 283; F. Sezgin, op. cit., vol. 6, p. 46.

[73] P. Duhem, *Le système du monde*, vol. 3, p. 284; F. Sezgin, op. cit., vol. 6, pp. 46–47.

[74] *Le système du monde*, vol. 3, pp. 286–287.

[75] F. Sezgin, op. cit., vol. 6, p. 47.

[76] P. Duhem, *Le système du monde*, vol. 3, pp. 327–345; F. Sezgin, op. cit., vol. 6, pp. 48–49.

[77] *Le système du monde*, vol. 3, p. 398.

Rušd as representatives of the concentric image of the world.[78]
The decision in favour of the teachings of Ptolemy and his Arab adherents was taken by another Franciscan, Bernardus de Virduno (late 13th c.) in Paris namely on the basis of Ibn al-Haiṯam's concept of solid spheres which he called "ymaginatio modernorum". With this, the victory of the Ptolemaic system with its eccentric spheres over that of al-Biṭrūǧī and Ibn Rušd was once and for all assured among the Franciscans.[79]
Among the Parisian scholars, Levi ben Gerson rejected from the traditions which his—mostly elder—colleagues cherished, particularly the homocentric system of spheres of al-Biṭrūǧī to whom he refers otherwise as the "master of the new principles of astronomy".[80] With him, something new makes its appearance in the Parisian school, namely the critique of the *Almagest*. It is well known that, while doing so, he uses once again the objections that his predecessor Ǧābir b. Aflaḥ had already raised.[81] Furthermore, Ben Gerson also leans on al-Kindī, Ṯābit b. Qurra, al-Battānī and others.[82]
Moreover, the other achievements connected with his name, such as the invention of the Camera obscura, of the Jacob's staff and of the law of the spherical sines as well as the formulation of the proof for the parallel postulate have long since been known from his Arabic predecessors.[83]
The practice of circulating the knowledge from the Arab astronomers in the form of pseudo-epigraphs can also be noticed in the 14th century. Duhem[84] demonstrated, for instance, that the tract *Demonstrationes Campani super theoricas* ascribed to Campanus of Novara (d.1296) is an inferior work from the 14th century which disseminated primarily the representation of the solid spheres by Ibn al-Haiṯam, although under a different name. What is particularly striking is the high esteem in which this representation of the solid spheres was held among the astronomers of the schools of Paris and Oxford. This is also the starting point for the well-known *Subtilissimae quaestiones in Libros de caelo et mundo* by Albert of Saxonia (ca. 1316-1390).[85]
The position of astronomy in Italy is described by Duhem in a masterly way.[86] The Italian astronomers had not participated in the debates [**14**] held in the 13th century in Paris and Oxford on the systems of Ptolemy and al-Biṭrūǧī. Only in the middle of the 14th century did this topic begin to interest them, and the debate lasted for about two centuries.
It is characteristic of the working method of astronomers in the 14th and 15th century in almost the entire Christian Occident that besides translations of Arabic sources, compilations and adaptations were also attempted. Although these made future work easier, they also through their own mistakes quite frequently again caused new mistakes among their successors. The most decisive effect of these mediating treatises, it appears to me, is that they result in the real authors and inventors falling into oblivion, since the sources are mostly passed over in silence. Moreover, from the 14th century onwards a battle of anti-Arabism is fought in full earnest. Not infrequently were works by al-Battānī, al-Farġānī, Ṯābit b. Qurra and Ibn al-Haiṯam cited as the *Almagest*.[87]
The narrow scope of this introduction requires us to leave unmentioned many topics which are not without importance. But at least the question of the relationship that Nicolaus Copernicus (1473-1543) had to Arabic-Islamic astronomy will be touched upon here. This leads us to the above-mentioned Byzantine transmission of Arabic sciences on their way to Europe. H. Usener was the first to detect traces of the reception transmitted along this path and he made known his findings in his *Ad historiam astronomiae symbola* (Bonn 1876). After a relatively long interruption, the subject again attracted the interest of research. Through a series of publications by David Pingree (since 1964) and from the Département d'études grecques, latines et orientales

[78] P. Duhem, op. cit., vol. 3, pp. 411–442; F. Sezgin, op. cit., vol. 6, p. 50.
[79] P. Duhem, op. cit., vol. 3, pp. 442–460; F. Sezgin, op. cit., vol. 6, p. 50.
[80] B.R. Goldstein, *Al-Biṭrūjī: On the Principles of Astronomy*, vol. 1, New Haven, London 1971, p. 40; F. Sezgin, op. cit., vol. 6, p. 52.
[81] P. Duhem, op. cit., vol. 5, p. 206; F. Sezgin, op. cit., vol. 6, p. 52.
[82] P. Duhem, op. cit., vol. 4, pp. 58–60; F. Sezgin, op. cit., vol. 6, pp. 52–53.
[83] F. Sezgin, op. cit., vol. 6, p. 53.
[84] P. Duhem, op. cit., vol. 4, pp. 119–124; F. Sezgin, op. cit., vol. 6, p. 53.
[85] P. Duhem, op. cit., vol. 4, pp. 151–157; F. Sezgin, op. cit., vol. 6, p. 53.
[86] P. Duhem, op. cit., vol. 4, p. 305; F. Sezgin, op. cit., vol. 6, p. 53.
[87] F. Sezgin, op. cit., vol. 6, pp. 53–54.

of the University of Louvain, we are today quite well informed about the working methods of the Byzantines and their treatment of Arabic sources.[88] It is possible that the Byzantines already had contacts with Arabic sciences in the 9th century, but with certainty in the 10th century. This happened at first in the older centres of sciences, such as Alexandria, Antioch, Aleppo, Damascus, Jerusalem and Palermo. From the 13th century places like Maragha and Tabriz were added. From there the path led via Erzurum and Trabzon (Trapezunt) to Constantinople and further to Italy, to Central and Eastern Europe. According to our present state of knowledge, a number of works were translated at different times from the Arabic into Byzantine-Greek. Quite frequently it so happened that new books came into circulation which carried the names of ancient Greek scholars as the authors, on the basis of Arabic material. In the field of astronomy J. Mogenet's view[89] is very revealing which states: "What the Byzantines lack is the proper understanding of the importance of the observations which the Arabs began from the moment they became acquainted with Ptolemy's work and continued until the end of the 12th century, and which they concretised in their tables that they continued to make available for discussion."

We now come to the question of the possible influence on Copernicus of Arabic-Islamic astronomers whose works can have reached him on the Persian-Byzantine path. The fact that Copernicus also stood in the tradition of dependence on Arabic-Islamic astronomers was realised particularly in the second half of the 20th century. It is not only connected with impulses for the changing of the geocentric system to the heliocentric one, or with the fact that he used[90] data and tables of his Arabic sources which were accessible in Latin translations and compilations, but rather it has to do with the fact that he must also have known the achievements of later Islamic astronomers of the 7th/13th and the 8th/14th century, even if their works, [**15**] as far as we know, have not been translated into Latin. He received the basic idea, namely to restore the principle of the uniform motion of the planets that had been impaired by Ptolemy, which led him finally to the decisive step, namely the heliocentric system, from those Arabic predecessors. There is also the fact that the attempts at solutions and the models of these scholars must also have reached Copernicus.

The common features ascertained so far between Copernicus and his Arab predecessors in the attempt to restore the principle of uniform motion of the planets can be summed up as follows:

1. Copernicus as well as Naṣīraddīn aṭ-Ṭūsī and Quṭbaddīn aš-Šīrāzī accept without reservation the principle that each planetary model requires as the basis a mechanism of motion where equal distances are covered by equal vectors with equal angular velocity.
2. Copernicus and his Arab predecessors equip their planetary model with a mechanism of a double vector with a length of half the eccentricity in order achieve the effect of the equant.
3. The lunar model of Copernicus is the same as that of Ibn aš-Šāṭir; both of them differ in their dimensions substantially from that of Ptolemy.
4. The model of Mercury by Copernicus is, with minor changes in the length of the vectors, the same as that of Ibn aš-Šāṭir.
5. Copernicus in the Mercury model uses the mechanism of aṭ-Ṭūsī's double epicycles which Ibn aš-Šāṭir also does.[91]

To explain this dependence, G. Rosińska[92] pointed out in 1973 that in the 15th century the achievements of Naṣīraddīn aṭ-Ṭūsī and Ibn aš-Šāṭir, which interest us here, must have been known to some extent in Cracow. Sandivogius of Czechel (1430) and Adalbert of Brudzevo (1482) are quite familiar with those theories as is evident from their commentaries on Gerhardus' *Theorica planetarum* and Peurbach's *Theoricae novae planetarum* respectively.

[88] v. F. Sezgin, op. cit., vol. 10, pp. 225–267; v. surtout Joseph Mogenet, *L'influence de l'astronomie arabe à Byzance du IX^e au XIV^e siècle*, in: Colloques d'histoire des sciences I (1972) and II (1973). Université de Louvain, Recueil de travaux d'histoire et de philologie, série 6, 9/1976/45–55.

[89] *L'influence de l'astronomie arabe à Byzance*, p. 55.

[90] v. p. ex. G.J. Toomer, *The Solar Theory of az-Zarqāl: A History of Errors*, in: Centaurus (Copenhagen) 14/1969/306–366, esp. p. 326; E. Rosen, *Copernicus and Al-Bitruji*, in: Centaurus 7/1961/152–156.

[91] F. Sezgin, op. cit., vol. 6, pp. 55–56.

[92] *Naṣīr al-Dīn al-Ṭūsī and Ibn al-Shāṭir in Cracow?*, in: Isis (Washington) 65/1974/239–243; F. Sezgin, op. cit., vol. 6, p. 56.

Some manuscripts of Greek translations of Persian astronomical works dealing with the new planetary theories are preserved in European libraries.[93]
The brief presentation of the connecting line between the European, Arabic-Islamic and Greek-Byzantine astronomers may be concluded here with Copernicus, and with a reference to the concrete example of the reconstructed instruments from the observatories of Maragha (ca. 1270), Istanbul (ca. 1574-1577) and that of Tycho Brahe on the island of Hven (1576-1597), which aim to make this connecting line visible.

[93] v. F. Sezgin, op. cit., vol. 6, pp. 56–57.

The Planetarium of as-Siǧzī

Our model:
Brass and wood, painted;
meridian ring tangentially movable.
7 planets with an inclination of 23.5°
arranged around the globe that can be rotated on its axis.
The globe is designed as a Ma'mūn-globe.
Total height: 1.63 m.
(Inventory No. A 1.05)

The Arabic-Islamic astronomers who believed that the Earth turns around itself included Abū Saʿīd Aḥmad b. Muḥammad as-Siǧzī[1] (2nd half of the 4th/10th c.). As al-Bīrūnī reports,[2] as-Siǧzī also constructed an astrolabe in the form of a boat (*al-asṭurlāb az-zauraqī*) according to the principle of the Earth's rotation. Whether as-Siǧzī himself built a planetarium is not known; our model serves to illustrate his ideas on the Earth's motion.

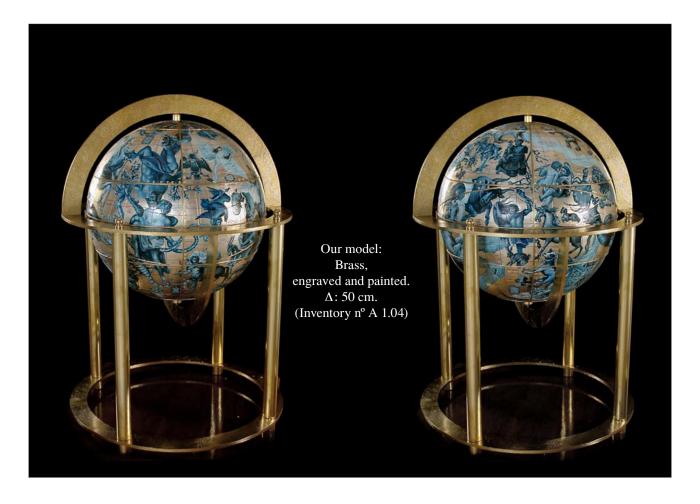
[1] v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 5, pp. 329–334; vol. 6, pp. 224–226.
[2] v. ibid., vol. 6, pp. 224.

The
Celestial Globe
of ʿAbdarraḥmān aṣ-Ṣūfī

ʿAbdarraḥmān b. ʿUmar b. Muḥammad aṣ-Ṣūfī[1] (b. 291/903, d. 376/986) is considered by modern research, together with Ptolemy and Argelander (d. 1875), to be one of the three great scholars in the field of fixed star astronomy. In comparison to Ptolemy, he enlarged the celestial atlas not only on the basis of the contributions by his Arabic predecessors and his own observations, but also furnished it with new data on the positions and grouped it according to new scales of brightness. As one of his contemporaries reports, there was in the year 435/1044 in Cairo a silver celestial globe which aṣ-Ṣūfī had constructed for the statesman ʿAḍudaddaula[2].

Our model was made according to the manuscript at Oxford, Bodleiana, Marsh 144. This was copied,[3] together with the illustrations of the constellations, by Ḥusain, a son of the author in the year 400/1010.

Aṣ-Ṣūfī gives two illustrations for each constellation. One shows it from the horizontal plane, the other is a reversed image of the first illustration, produced by tracing through the former.

Our model:
Brass globe, diameter: 50 cm,
pivoted in a massive stand on which
the coordinates of the star positions can be read.
Stars inlaid in silver.
Arabic letters with their numerical value.
(Inventory No. A 1.02)

[1] v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 6, pp. 212–213.

[2] v. Ibn al-Qifṭī, *Taʾrīḫ al-ḥukamāʾ*, ed. J. Lippert, Leipzig 1903, p. 440.

[3] The manuscrit was published in facsimil by the Institute for the History of Arabic-Islamic Science, Frankfurt 1986.

Our model:
Brass,
engraved and painted.
Δ: 50 cm.
(Inventory nº A 1.04)

The Celestial globe of Coronelli

The Franciscan priest Vincenzo Coronelli (1650-1718), who had made a name for himself as a cartographer and globe maker, produced a celestial globe with a diameter of 3.85 m for Louis XIV. The star map inscribed on it is based on the depiction of ʿAbdarraḥmān aṣ-Ṣūfī (4th/10th c., above, p. 7). The fourteen constellation figures in the southern hemisphere are based on subsequently acquired knowledge. The work on the globe was executed between 1681 and 1683 in Paris. The constellations figures were painted by Jean-Baptiste Corneille (1649-1695). They are painted on papier-mâché. The names of the constellations are written in Greek, Latin, French and Arabic.
The original made for Louis XIV is preserved today in the Bibliothèque nationale in Paris. It must have been very popular, because some 60 smaller replicas with a diameter of 110 cm exist so far in European museums and libraries.
The construction of our model was made possible through a CD-Rom published by the Bibliothèque nationale.[1]

[1] *Coronelli. Les globes de Louis XIV.* Collection Bibliothèque nationale de France, Sources. Coordination scientifique: Monique Pelletier, Paris 1999. On the literature v. P. Kunitzsch, *The Arabic Nomenclature on Coronelli's 110 cm Celestial Globes*, in: Zeitschrift für Geschichte der arabisch–islamischen Wissenschaften (Frankfurt) 9/1994/91–98; idem, *Neuzeitliche europäische Himmelsgloben mit arabischen Inschriften*, in: Sitzungsberichte der Bayerischen Akademie der Wissenschaften, Philologisch-historische Klasse, Munich 1997, fasc. 4, esp. pp. 16–25; idem, *Coronelli's Great Celestial Globe Made for Louis XIV: the Nomenclature*, in: Zeitschrift für Geschichte der arabisch–islamischen Wissenschaften (Frankfurt) 14/2001/39–55; M. Milanesi, *Coronelli's Large Celestial Printed Globes: a Complicated History*, in: Der Globusfreund (Vienna) 47–48/1999–2000/143–160 (German translation R. Schmidt, op. cit., pp. 161–169).

OBSERVATORIES

Perhaps there is no other field of astronomy—neither that of the constantly improving instrumentation, nor the literary genre of the tables of observations, nor the finely honed theoretical models which come ever closer to reality—that can help us so well to understand the decisive steps of development in this science, developing from the contributions of individual culture areas than that of the observatories. The question that has been raised again and again for the last two hundred years about traces of the possible existence of an "institution" of observatories prior to Islam was answered in 1931 by Ernst Zinner,[1] one of the most renowned historians of astronomy, in the following words: "No observatories like those of the Babylonians existed or, if they did, at the most, only for a short time, since the prerequisites, namely the compulsion to watch all the celestial phenomena for centuries, were absent among the Greeks. Here we have instead the activity of individuals who according to their preference paid attention to one or the other celestial phenomenon. It is reported that Eudoxus had an observatory near Heliopolis and later on Knidos, obviously influenced by the Egyptians. For centuries, an equatorial ring was to be seen in the rectangular hall in Alexandria and was probably used for teaching; but that cannot be taken to be an observatory. Hipparchus could take his observations with portable instruments. Likewise, as far as the observations by Ptolemy are concerned, we should neither assume a stationary installation of instruments nor the existence of an observatory." "It is remarkable that the generosity of the Ptolemaic rulers did not connect their name with an observatory. Nor is there any report of any of the many wealthy men of Antiquity making a name for themselves through the establishment of an observatory. Their partiality for science exhausted itself in donations of clocks."

Zinner describes the situation to the point. We can quite agree with his reasoning as well. But his reproachful remark that none of the Ptolemaic rulers and none of the wealthy men of Antiquity had made a name for themselves by founding an observatory does not seem quite fair. Of course, astronomy cultivated for millennia in diverse cultures had reached a high standard under the Greeks and particularly with Ptolemy, but the development of the subject had not yet advanced so far and the overall conditions were not yet so favourable that a ruler or a statesman would have hit upon the idea that there was any necessity for establishing an observatory. We can understand this state of affairs better if the details of the process of the origin of the first two regular observatories established in Islam are known. An excellent book by Aydın Sayılı that appeared in 1960 in Ankara under the title The Observatory in Islam and its Place in the General History of the Observatory saves us the trouble of investigating the history of its origins. It is particularly striking that the foundation of the Baghdad observatory in the aš-Šammāsīya quarter and of the Damascus observatory on Mount Qāsiyūn could be only realised in the last five or six years of Caliph al-Maʾmūn's reign (ruled 198/813-218/833).[2] The reports in question indicate that Caliph al-Maʾmūn, who occupied himself with astronomy and used to commission and even take part himself in the astronomical observations and measurements which he considered important and who had the necessary instruments constructed, did not entertain the idea of an observatory for a long time. It appears that the more intensified astronomical work, the increasing number of astronomers participating in it and the gradually enlarged range of instruments, the fact that the maintenance of the instruments and making them available for observations had to be assured, and especially the increased urge for enlarging and

[1] *Die Geschichte der Sternkunde von den ersten Anfängen bis zur Gegenwart*, Berlin 1931, p. 149.

[2] A. Sayılı, op. cit., pp. 50–87.

improving the measuring instruments [**20**] finally made it unavoidable that a suitable building was set aside for the observatory. What is remarkable in the report on the origin of the observatory at aš-Šammāsīya is that it consisted of a former temple, more likely a synagogue.[3] It was set up under the supervision of the converted Jew, Sind b. ʿAlī,[4] who belonged to the closest circle of astronomers around the Caliph. The astronomical work was becoming difficult to accomplish without a suitable building and the Caliph's state of health was deteriorating: perhaps it was both these factors that led to this step. In this connection it should to be noted that a (former) sacral building was also used for the observatory on the Qāsiyūn near Damascus, in this case the monastery Dair al-Murrān.[5] Moreover, both observatories were established shortly after one another, almost about the same time. Perhaps the desire to be able to do simultaneous observations or to achieve comparative values independently from each other by eminent astronomers using first rate instruments also played a role. As early as in 1877 L.-A. Sedillot[6] pointed to an observation which was possibly carried out in both places at the same time. The accounts preserved for us show that almost all the great astronomers of the time were working in the two observatories. These included Yaḥyā b. Abī Manṣūr, al-ʿAbbās b. Saʿīd al-Ǧauharī, Muḥammad b. Mūsā al-Ḫwārizmī, Ḫālid b. ʿAbdalmalik al-Marwarrūḏī and Sind b. ʿAlī. Sind b. ʿAlī's manifold duties included the improvement of the observational instruments (*iṣlāḥ ālāt ar-raṣad*).[7] The famous astronomer Aḥmad b. ʿAbdallāh Ḥabaš,[8] a younger contemporary of the above-mentioned astronomers, informs us that al-Maʾmūn ordered the astronomer Ḫālid b. ʿAbdalmalik al-Marwarrūḏī to observe the celestial bodies with the best possible instruments at the observatory of Damascus for a whole year.[9] One of the most interesting examples of the active interest taken by the Caliph personally in the equipment and instruments in his observatories is reported by al-Bīrūnī:[10] al-Maʾmūn had an iron gnomon of ca. 5 m (10 ells) length erected on the Qāsiyūn (Dair Murrān). He had it justified in the daytime and measured again at night, and because of the difference in temperature he found it shorter by a "barley-corn" (*šaʿīra*). He was disappointed that therefore this gnomon could not be used for determining the precise length of the year.

Further developments

Astronomers and admirers of astronomy had become aware of the function, the purpose and the task of an observatory through the forerunners at Baghdad and Damascus. One and a half centuries later the first successor appeared. It was erected by the Buyid ruler Šarafaddaula Abu l-Fawāris Šīrḏīl (ruled 372/983-379/989) in 378/988, once again at Baghdad. The founder desired that in this solid building erected for this purpose, the astronomical observations of the heavens and of the planets were to be continued in the same way as they had been begun under al-Maʾmūn. Šarafaddaula had entrusted the supervision of the observatory to the well-known astronomer and mathematician Abū Sahl Waiǧan b. Rustam al-Kūhī.[11] On the shape of the observatory we learn from al-Bīrūnī[12] that it had a dome with a diameter of ca. 12.5 m (25 ells) in the centre of which an opening had been left for the [**21**] entry of the Sun's rays so that the course of the Sun could be followed daily. Not longer than six years after the foundation of the second observatory

[3] V. Ibn an-Nadīm, *Fihrist*, p. 275; Ibn al-Qifṭī, *Taʾrīḫ al-ḥukamāʾ*, Leipzig 1903, pp. 206–207; A. Sayılı, op. cit., pp. 51-52.
[4] V. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 5, p. 242–243; vol. 6, p. 138.
[5] V. A. Sayılı, op. cit., p. 57.
[6] *Histoire générale des Arabes. Leur empire, leur civilisation, leurs écoles philosophiques, scientifiques et littéraires*, vol. 2, Paris 1877 (reprint Paris 1984), p. 8, 186; cf. A. Sayılı, op. cit., p. 56.
[7] Ibn al-Qifṭī, *Taʾrīḫ al-ḥukamāʾ*, p. 206.
[8] V. F. Sezgin, op. cit., vol. 6, pp. 173–175.
[9] Ḥabaš, *az-Zīǧ*, ms. Yeni Cami 784/2, fol. 70b; A. Sayılı, *The Introductory Section of Ḥabash's Astronomical Tables Known as the ‹Damascene› Zīj* (English translation), in: Ankara Üniversitesi Dil ve Tarih-Coğrafya Fakültesi Dergisi 13, 4/1955/139–151, esp. pp. 142–143, 150; A. Sayılı, *The Observatory in Islam*, p. 57.
[10] *al-Qānūn al-Masʿūdī*, vol. 2, Haidarabad 1374/1955, p. 637; A. Sayılı, *The Observatory in Islam*, pp. 72–73.
[11] V. Ibn al-Qifṭī, *Taʾrīḫ al-ḥukamāʾ*, p. 351; A. Sayılı, *The Observatory in Islam*, pp. 112–117.
[12] *Taḥdīd nihāyāt al-amākin*, p. 101; A. Sayılı, op. cit., p. 116.

in Baghdad, Faḫraddaula Abu l-Ḥasan ʿAlī b. Ruknaddaula, another Buyid (ruled 366/976-387/997), fulfilled the wish of the astronomer Ḥāmid b. al-Ḫiḍr al-Ḫuǧandī and had a special observatory erected in 384/994 in Raiy (in the south of today's Tehran). The sextant constructed into it with a radius of ca. 20 m with its division into minutes and seconds was to make possible an extremely accurate measurement of the position of the Sun, for ascertaining whether the obliquity of the ecliptic remains constant, decreases or increases[13] (see below, p. 25).

About a quarter century afterwards an observatory was established in Hamadan, apparently by ʿAlāʾaddaula b. Kākūyā, a local ruler of the provinces of Isfahan, Hamadan and Yazd (ruled 398/1007-434/1041). Abū ʿAlī Ibn Sīnā, who was on friendly terms with him, is said to have complained to him that the common ephemerides made on the basis of obsolete astronomical observations were imperfect. Thereupon Amīr ʿAlāʾaddaula gave the order to deal with the problem of observation in greater detail and made the required financial means available. It is said that Ibn Sīnā undertook the task and his pupil Abū ʿUbaid al-Ǧūzaǧānī was responsible for the production of the required instruments. Although observations were frequently interrupted by journeys (with ʿAlāʾaddaula) and other impediments, Ibn Sīnā recorded the results all the same in his Kitāb al-ʿAlāʾī.[14] We do not learn the exact details about the building of the observatory, but the content of the brief report permits us to assume that it was a building suitable for the purpose in which the observations were carried out. This is confirmed by a further report[15] from which it becomes clear that instruments not known until then were also developed for this purpose. Moreover, the observational instrument with its large dimensions (below, p. 26), which Ibn Sīnā himself described in a special treatise, can be visualised only in the scope of an observatory.[16]

Some forty years after the erection of the observatory by ʿAlāʾaddaula, another observatory arose in Persia, this time at the behest of the Seljuk Malikšāh b. Alparslan (ruled 465/1072-485/1092). As the historian Ibn al-Aṯīr[17] reports, it was already founded in 467/1075 and some of the eminent astronomers of the time like ʿUmar b. Ibrāhīm al-Ḫaiyām, Abu l-Muẓaffar al-Isfizārī or Maimūn b. an-Naǧīb al-Wāsiṭī are said to have worked there. The location of the observatory is not mentioned. Modern scholars assume that it could have been Isfahan, Nishapur or Raiy. Perhaps the observation of the heavens ordered by the founder of the observatory was continued after his death. According to one report the observatory is said to have been active for another thirty years.[18] According to our knowledge the first observatory built in northern Africa goes back to the early 6th/12th century. It was founded in Egypt under the Fatimid al-Āmir bi-aḥkāmillāh Abū ʿAlī al-Manṣūr (ruled 495/1101-524/1130). The initiator was the vizier al-Afḍal Abu l-Qāsim Šāhinšāh b. Amīr al-ǧuyūš Badr (d. 515/1121); it was completed by his successor Abū ʿAbdallāh al-Maʾmūn al-Baṭāʾiḥī (d. 519/1125). About the complicated and unfortunate history of this observatory the historian Taqīyaddīn al-Maqrīzī (d. 849/1441) reports in his *al-Ḫiṭaṭ*[19] from an anonymous book about the building (*Kitāb ʿAmal ar-raṣad*). The vizier al-Afḍal is said to have been motivated to take the decision to found an observatory in Cairo when some 100 ephemerides for the years [**22**] after 500/1107 had been brought to him from Syria and when he realised that these differed from the data produced by his own astronomers. In order to correct the errors, the astrono-

[13] V. A. Sayılı, op. cit., pp. 118–121; F. Sezgin, op. cit., vol. 6, pp. 220–221.

[14] Ẓahīraddīn ʿAlī b. Abi l-Qāsim al-Baihaqī, *Tatimmat Ṣiwān al-ḥikma*, Lahore 1935, p. 52.

[15] Ibn al-Qifṭī, *Taʾrīḫ al-ḥukamāʾ,* p. 422; A. Sayılı, op. cit., pp. 156–157.

[16] E. Wiedemann, *Über ein von Ibn Sînâ (Avicenna) hergestelltes Beobachtungsinstrument*, in: Zeitschrift für Instrumentenkunde (Brunswick) 45/1925/269–275 (reprint in: E. Wiedemann, *Gesammelte Schriften*, vol. 2, pp. 1110–1116 and in: Islamic Mathematics and Astronomy, vol. 92, Frankfurt 1998, pp. 129–135).

[17] ʿIzzaddīn ʿAlī b. Muḥammad Ibn al-Aṯīr, *al-Kāmil* fi *t-taʾrīḫ*, vol. 10, Beirut 1966, p. 98.

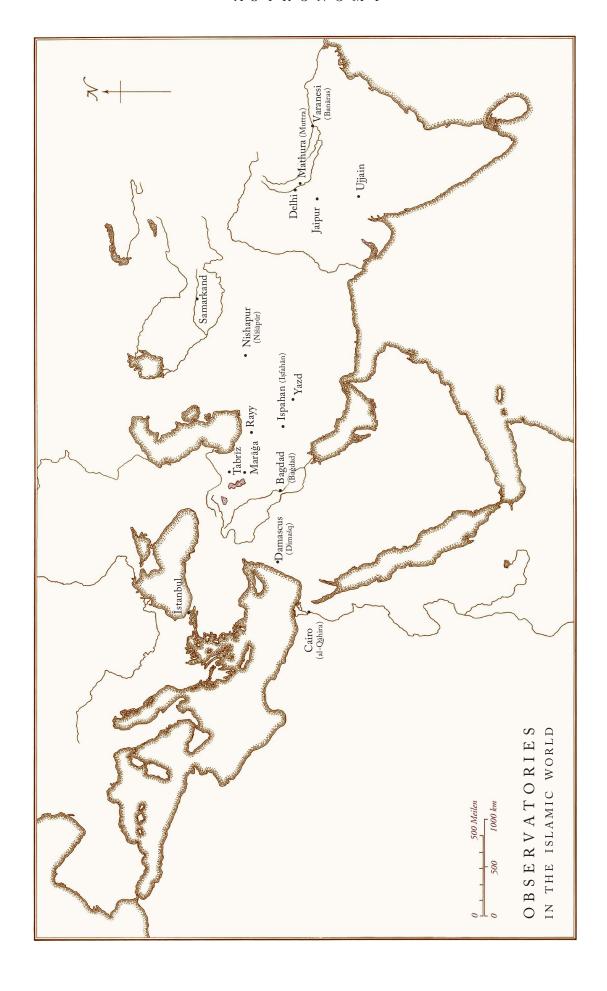
[18] V. A. Sayılı, op. cit., pp. 160–166, esp. p. 166.

[19] *Kitāb al-Mawāʿiẓ wa-l-iʿtibār bi-ḏikr al-ḫiṭaṭ wa-l-āṯār*, vol. 1, Cairo, 1270/1854, pp. 125–128, German summary by E. Wiedemann, *Zur islamischen Astronomie*, in: Sirius (Leipzig) 52/1919/122–127 (reprint in: *Gesammelte Schriften*, vol. 2, pp. 905–911 and in: Islamic Mathematics and Astronomy, vol. 92, Frankfurt 1998, pp. 77–83).

mers advised the building of an observatory. The task was entrusted to the physician and astronomer Abū Saʿīd Ibn Qaraqa. The difficulties encountered during the manufacture of the large observational ring of copper with a diameter of about 5 m, which was meant for measuring the azimuth correct to a minute are described at length. Apparently, this instrument was modelled after the device (with a diameter of 3.5 m) constructed by Ibn Sīnā about a hundred years earlier, although perhaps without the arm for the measurement of altitudes. Ibn Qaraqa also made one more smaller device for the same purpose with a diameter of 3.5 m (and perhaps with the arm for the measurement of altitudes ?). The instruments with large dimensions built or planned for the observatory also included an armillary sphere (*ḏāt al-ḥalaq*) with a diameter of about 2.5 m (5 ells). The originally planned location for the observatory on the terrace of the Ǧāmiʿ al-Fīla ("Elephant Mosque") was abandoned and the large ring was transported with great difficulty to the terrace of another mosque, the Masǧid al-Ǧuyūšī. The vizier al-Maʾmūn al-Baṭāʾiḥī identified himself so much with the observatory that he called it *ar-Raṣad al-Maʾmūnī al-muṣaḥḥaḥ*, a successor, as it were, to the former *ar-Raṣad al-Maʾmūnī al-mumtaḥan* of Caliph al-Maʾmūn in Baghdad. This is said to have been one of the reasons why the Caliph took the vizier into custody and ordered the stoppage of the work on the observatory. In connection with the construction of this observatory in Cairo, two anecdotes are reported which we repeat here after E. Wiedemann's translation because of their importance for the history of astronomical instruments. The vizier al-Afḍal inspected the progress in the work of manufacturing the large azimuth ring every day. On the day of the completion, while hot copper was being poured into the mould, it turned out that "some moisture had remained at one spot in the mould. When the molten copper reached this spot, it caused the wet spot to crack so that the ring was imperfect. After it had cooled down and was exposed it turned out to be flawless, except for that particular spot. Afḍal was very angry about the failure, but let himself be pacified, when Ibn Qaraqa pointed out that with an instrument of dimensions such as had never been manufactured before we should be content if its manufacture succeeded even after ten attempts."[20]

The second anecdote narrates that al-Afḍal said to the leader of the project, Ibn Qaraqa: "'If you had made the circle smaller, then the work would have been easier.' Ibn Qaraqa replied: 'If I could have made it of such size that one of its extremities were at the Pyramids and the other at the Tannūr (a place near Cairo), I certainly would have done so. The larger the instruments, the greater the exactness of the observations. What, in fact, is the dimension of an instrument compared with the vastness of the celestial world!'"[21]

The statements on the observatories were collected by Aydın Sayılı with remarkable diligence and a vast knowledge of the sources; he accomplished this difficult task admirably. His material and some of his remarks create the impression that our sources as a rule report only on those observatories whose foundation was connected with spectacular events or with the construction of instruments of extraordinary dimensions. Moreover, the term *raṣad* used for observatory also means "observation" which causes some difficulties in the assessment of the relevant statements. Thus the frequently occurring sentence *ʿamala r-raṣad* can be understood both in the sense of "he built the observatory" and "he observed." This contributes to the fact that, despite Sayılı's excellent work, a complete record of the Arabic-Islamic observatories remains practically illusory. Under [**23**] these constraints, Sayılı's view[22] seems to be correct that the countries of the Maghrib and Islamic Spain did not keep up with the developments which the observatory had attained in the eastern part of the Islamic world, and remained at best at the level of al-Maʾmūn's period. Like many other areas of science, the observatory with its institutions and instrumentation also reached a remarkable climax in its development in the 7th/13th century. The importance of the observatory founded in Maragha with its highly developed and partly newly designed instruments for the general history of science has not yet been adequately evaluated (see below, p. 38 ff.). This observatory and its successors in Samarqand (below, p. 69 ff.) and

[20] al-Maqrīzī, *al-Ḫiṭaṭ*, vol. 1, p. 126; E. Wiedemann, *Zur islamischen Astronomie*, p. 124 (reprint in: *Gesammelte Schriften*, p. 908; Islamic Mathematics and Astronomy, vol. 92, p. 80).

[21] al-Maqrīzī, *al-Ḫiṭaṭ*, vol. 1, p. 127; E. Wiedemann, *Zur islamischen Astronomie*, p. 126 (reprint in: *Gesammelte Schriften*, p. 910; Islamic Mathematics and Astronomy, vol. 92, p. 82); A. Sayılı, op. cit., p. 170.

[22] A. Sayılı, op. cit., p. 398.

Istanbul (below, p. 53 ff.) are the institutions that led to the establishment of the first observatories proper in Europe. On the same path on which the knowledge of those observatories reached Europe, further new achievements, new theories of science and manuscripts of scientific works also travelled from the eastern part of the Islamic world to the Occident. Thus, in this connection we can hardly overestimate the importance of the fact that the original of the celestial globe from the Maragha observatory has been preserved at Dresden since at least 1562.

THE OBSERVATORY OF RAIY (OLD TEHERAN)

Abū Maḥmūd Ḥāmid b. al-Ḫiḍr al-Ḫuǧandī (2nd half of 4th/10th c.), one of the most eminent mathematicians and astronomers of his time, had noticed that the values of the obliquity of the ecliptic had apparently decreased since the time of Ptolemy and of the Indian sources up to his day. In order to determine the same as accurately as possible, he built a special observatory in the city of Raiy (the old Raghae in the south of Tehran), which the Buyid prince Faḫraddaula (ruled 366/976-387/997) funded. The sextant of the circle constructed in it for the observation of the solar altitude at the solstices was named "Faḫrī sextant" after the patron.
"Our sextant consists of two vertical walls erected along the meridian at a distance of 7 ells (3.5 m). At the uppermost part, that is to say, 20 ells (10 m) above ground, there is a dome; in it is an opening with a diameter of 1/6 ell (1/12 m). Above the opening is fastened an iron rod, and from it is suspended a high rectangular box made of planks with two rings at one end. It is 20 m long. With it as the radius, a sixth of a circle is described; this begins vertically under the opening at a depth of 10 m and reaches up to ground level. The circle is carefully smoothened and covered with planks. It is divided into degrees and each degree again into 360 parts, i.e. into minutes and then into 10 seconds each. A circular disc with two perpendicularly intersecting diameters serves to intercept the Sun's image and to determine exactly the position of the image which will have large dimensions because of the great distance of the aperture from the partition."[1]

Our model: Scale ca. 1 : 30.
Base plate 100 × 70 cm, wood, laminated
(Inventory No. A 5.03)

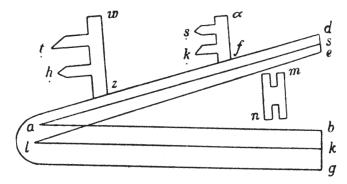
With the help of the sextant al-Ḫuǧandī could convince himself of the continuous reduction in the obliquity of the ecliptic.

See also F. Sezgin, *Geschichte des arabischen Schrifttums,* vol. 6, pp. 220–221, 269; J.A. Repsold, *Zur Geschichte der astronomischen Meßwerkzeuge. Nachträge*, in: Astronomische Nachrichten (Kiel) 206/1918/col. 125–138, esp. pp. 134–135 (reprint in: Islamic Mathematics and Astronomy, vol. 88, Frankfurt 1998, p. 16–22, esp. pp. 20–21).

[1] Al-Bīrūnī, *Ḥikāyat al-āla al-musammāt as-suds al-faḫrī*, v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 6, p. 269; translated by E. Wiedemann, *Über den Sextanten des al-Chogendî*, in: Archiv für Geschichte der Naturwissenschaften und der Technik (Leipzig) 2/1910/149–151, esp. pp. 149–150; reprint in: Islamic Mathematics and Astronomy, vol. 92, Frankfurt 1998, pp. 55–57, esp. pp. 55–56.

Main instrument

of the observatory of ʿAlāʾaddaula
(ca. 414/1023) in Hamaḏān

Our model:
Wood, laminated.
Diameter: 36 cm.
Scales and diopters of gilded brass.
(Inventory No. A 5.06)

In the observational instrument (*āla raṣadīya*)[1] developed by Abū ʿAlī al-Ḥusain b. ʿAbdallāh Ibn Sīnā (d. 428/1037) for ʿAlāʾaddaula's observatory, recent research sees the early use of the principle of angular measurement as it later became common with the Jacob's staff.[2] With this instrument astronomical altitudes were to be [**27**] ascertained as accurately as possible. Its long arms make possible an observational result that can be read off not only in degrees, but in minutes and seconds as well. For this purpose Ibn Sīnā chose the length of the arm of ca. 7 m.

[1] Eilhard Wiedemann, *Über ein von Ibn Sînâ (Avicenna) hergestelltes Beobachtungsinstrumen*t, in: Zeitschrift für Instrumentenkunde (Brunswick) 45/1925/269–275; idem (avec la collaboration de Th.W. Juynboll), *Avicennas Schrift über ein von ihm ersonnenes Beobachtungsinstrument*, in: Acta orientalia (Leyde) 5/1926/81–167 (reprint des deux travaux in: E. Wiedemann, *Gesammelte Schriften*, vol. 2, S. 1110–1203 and in: Islamic Mathematics and Astronomy, vol. 92, Frankfurt 1998, pp. 129–223); F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 6, pp. 276–278.

[2] Fritz Schmidt, *Geschichte der geodätischen Instrumente und Verfahren im Altertum und Mittelalter*, Erlangen 1929 (reprint in: Islamic Mathematics and Astronomy, vol. 89, Frankfurt 1998), p. 341; F. Sezgin, *Qaḍīyat iktišāf al-āla ar-raṣadīya ‹ʿaṣā Yaʿqūb›*, in: Zeitschrift für Geschichte der arabisch-islamischen Wissenschaften (Frankfurt) 2/1985/partie arabe, pp. 7–30.

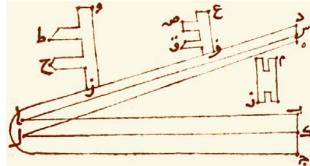



Fig. in Wiedemann.

Fig. in Ibn Sīnā

"On the upper arm two attachments are fastened, *wz* and *af*, both of exactly the same size and shape. The figure in the text erroneously draws them differently. Both consist of a vertical piece to which two pieces each are attached on the side. The upper attachment must be cut below in such a way that it sits astride the arm and that it moves so tightly that it does not shake in the least. With the upper attachment special care should be taken so that it always remains vertical, that is to say, it does not tilt. The ends of the attachments *ḥṭ* and *ṣḳ* are taped to a point; sight holes are bored into the flat surface of the attachments. The two pointed tips, or the two holes of each attachment, must lie exactly one above other, and remain in both the attachments at the same height above the surface of the arm. Objects with weak light are generally sighted above the pointed tips; so are those with strong light for the sake of orientation; these tips represent, so to say, the finder attached to our large telescopes. The holes then serve for finer measurement. The side pieces thus attached to the vertical plates, which correspond to the sight vanes, are found in no other instrument known to me."

"An advantage of this arrangement is that it is not necessary to bend over the instrument while observing, which can be very uncomfortable. Instead we look from the side along the upper arm, parallel to its length, towards the object. … The attachment mn then slides between the two arms."[3]

The angle to be defined, which represents the altitude of the observed celestial body, is found by the trigonometric ratio between the two arms, which are furnished with scales. The instrument is not simply placed on the floor, but its apex is loosely pivoted to a circular pillar at the centre of a horizontal cylindrical wall. Thus the device can be used also for determining the azimuth, a function which Ibn Sīnā also describes clearly.[4]

Finally he emphasises that the ground under the device must be absolutely horizontal. For levelling, he recommends the use of a basin filled with coloured water (see below, vol. III, p. 141).

[3] E. Wiedemann, *Über ein von Ibn Sînâ (Avicenna) hergestelltes Beobachtungsinstrument*, pp. 272–273 (*Gesammelte Schriften*, vol. 2, pp. 1113–1114).

[4] E. Wiedemann, *Avicennas Schrift über ein von ihm ersonnenes Beobachtungsinstrument*, pp. 115–116 (*Gesammelte Schriften*, vol. 2, pp. 1151–1152).

THE THREE OBSERVATORIES OF MARĀĠA, ISTANBUL AND HVEEN

1.

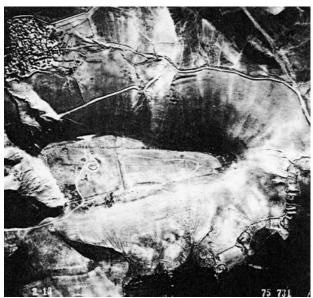
Marāġa:

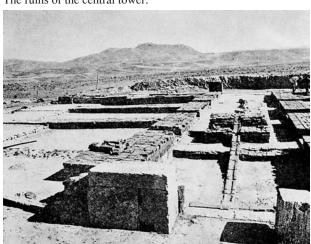
After the conquest of Baghdad in 1258, where the old Abbasid observatory existed for about 450 years, the ruler Hülegü commissioned the scholar Naṣīraddīn aṭ-Ṭūsī (d. 672/1274) with building a new observatory in Maragha, the capital of the western Mongol empire. According to one tradition the initiative for the foundation of an observatory in Maragha is said to have come from Möngke, the Great Khan and Hülegü's brother. It is more likely that the plan originated from Naṣīraddīn himself.[1]
The construction of the observatory began in 1259; it is not known when it was completed. Presumably it already became operational around 1270, i.e. a few years after Hülegü's death (1265).
The observatory was situated ca. 80 km south of Tabriz and 29 km east of Lake Urmia. It was erected on a hill, whose length lies exactly on the meridian. Around 1880 there were to be seen of it "only the foundations of the 4 1/2 - 5 feet [= ca. 1.5 m] thick walls and a few circular heaps of rubble," as A. Houtum-Schindler[2] reports, who drew a ground plan of the ruins according to the knowledge of those days (see annexed figure).

Ground plan of the Maragha observatory (ca.1270) after Houtum-Schindler.

[1] Aydın Sayılı, *The Observatory in Islam and its Place in the General History of the Observatory*, Ankara 1960 (reprint in: Islamic Mathematics and Astronomy, vol. 97, Frankfurt 1998), p. 190.

[2] *Reisen im nordwestlichen Persien 1880–82*, in: Zeitschrift der Gesellschaft für Erdkunde (Berlin) 18/1833/320–344, esp. 338 and plate No. 6; Hugo J. Seemann, *Die Instrumente der Sternwarte zu Marâgha nach den Mitteilungen von al-ʿUrḍî*, in: Sitzungsberichte der Physikalisch–medizinischen Sozietät zu Erlangen 60/1928/15–126, esp. p. 116 (reprint in: Islamic Mathematics and Astronomy, vol. 51, Frankfurt 1998, pp. 81–192, esp.. p. 182).

Today we have at our disposal a detailed plan and a rather fair knowledge of the construction of the observatory, thanks to the excavations conducted in 1972, 1975 and 1976 under the supervision of Parviz Vardjavand.[3]
The hill on which the observatory was erected is even today called Raṣad dāġī ("observatory mountain"). It lies ca. 500 m to the north of the last houses of the city of Maragha, is 512 m long, 220 m wide and 110 m high.
The parts of the whole complex revealed through the excavations, called "16 unités différentes" by Vardjavand, are named by him as follows:

A) East-west and north-south walls.
B) Central tower of the observatory.
C) Five circular units.
D) Rectangular hall.
E) Library (?).
F) Conference hall.
G) Workshop.
H) Building with the central iwan.
I) Stone pavement.
J) Village settlement from the time after the destruction of the observatory.

On these units, he provides the following details:
The hill of the observatory is divided into two parts through a wall 139 m long and 1.10 m wide.
1) The southern part containing all the buildings and the places meant for the observatory instruments has a surface area of 280 × 220 m.
2) The northern part is ca. 220 m long, its width diminishes towards the north and varies between 220 m and 50 m.
The central tower has a diameter of 28 m. Of the sextant installed therein and of the stairs built on both sides, only a part of 5.55 m survives. But it becomes clear from the ruins that this sextant was not partially constructed underground, as those of the observatories of Raiy and Samarqand were. Its radius probably measured between 10 m and 12 m.
The other five circular foundations seem to indicate the ruins of cylindrical towers in which astronomical observations were carried out with special large instruments like the armillary sphere, the mural quadrant, the solstitial armilla and the equinoctial armilla. The extant ruins also indicate the foundation of a library mentioned in the historical sources. The rooms in the central tower, on both sides of the sextant, were probably working places and living quarters of the astronomers.

Photos from P. Vardjavand, *Rapport préliminaire sur les fouilles de l'observatoire de Marâqe*.

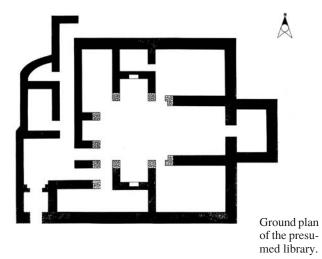
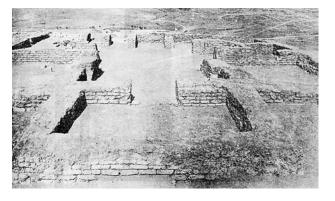
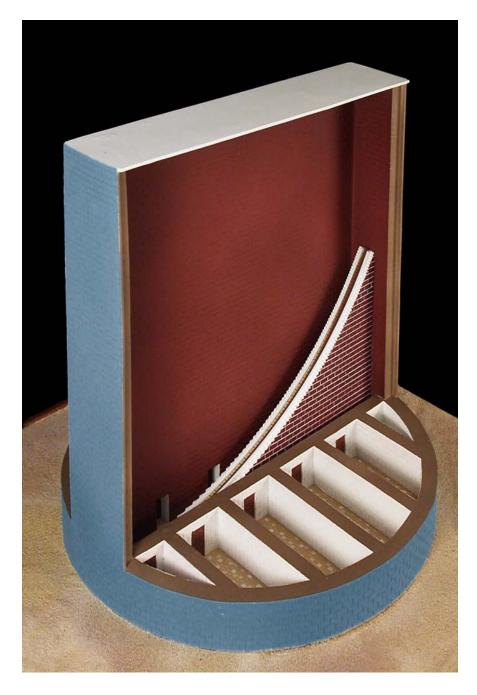
Aerial view of the hill with the Maragha observatory.

The ruins of the central tower.

[3] P. Vardjavand, *Rapport préliminaire sur les fouilles de l'observatoire de Marâqe*, in: Le monde iranien et l'islam. Sociétés et cultures, vol. 3, Paris 1975, pp. 119–124 and 5 pl.; idem, *La découverte archéologique du complexe scientifique de l'observatoire de Maraqé*, in: International Symposium on the Observatories in Islam 19–23 September, 1977, ed. M. Dizer, Istanbul 1980, pp. 143–163.

The hill of the observatory seen from the plain.

The ground plan of the central tower with the sextant.

The ground plan of the entire complex of the observatory, oriented to the north.

The foundations of one of the five smaller towers which were probably meant for observations with special large instruments.

The ruins of the sextant in the middle of the tower, towards the north.

The ruins of the sextant, towards the south.

Ground plan of the presumed library.

Foundation walls of the building that was presumably the library.

Our model:
wood, laminated.
Diameter: 50 cm.
Scale: 1:56.
Base plate: 80 × 80 cm.
(Inventory No. A 5.05).

Reconstruction of the

Great Sextant

in the central tower
of the observatory of Marāġa

after the ruins of the original building:
diameter of the tower: 28 m,
radius: ca. 10-12 m.

Apart from Naṣīraddīn aṭ-Ṭūsī, the other astronomers working at the observatory were Muḥyiddīn b. Abi š-Šukr al-Maġribī, Mu'aiyadaddīn al-ʿUrḍī, Aṯīraddīn al-Abharī, Naǧmaddīn Dabīrān and Faḫraddīn al-Ḫilāṭī.[1]

The astronomical achievements of this school included new astronomical tables under the title *Zīǧ-i Īlḫānī* in which not only contemporary results of observations were registered but also corrected longitudes and latitudes of localities around Maragha. From the point of view of the history of mathematical geography it is of the greatest importance that at this observatory, obviously as a consequence of the close collaboration between the two great astronomers, Naṣīraddīn aṭ-Ṭūsī from the east of the Islamic world and Muḥyiddīn b. Abi š-Šukr al-Maġribī from the west, a form of integration was achieved between the eastern longitudes counted from a zero meridian that ran through Baghdad, and the western longitudes reckoned from a zero meridian that had been shifted by 28°30' to the west of Toledo.[2]

A lasting influence on the subsequent development of astronomy began from the instruments constructed for the Maragha observatory. It was a particularly advantageous arrangement that Mu'aiyadaddīn al-ʿUrḍī could be won over for this purpose, who had already made a name for himself in Damascus through important achievements in the field of the construction of astronomical devices.

The instruments of the Maragha observatory are, unfortunately, lost without a trace, with the exception of the celestial globe which Muḥammad, the son of Mu'aiyadaddīn al-ʿUrḍī, constructed. Fortunately, a detailed description written by Mu'aiyadaddīn himself and preserved in several copies makes it possible for us to gain a precise idea of those instruments, and to reconstruct them.

Mu'aiyadaddīn al-ʿUrḍī describes ten instruments, mentioning three of them expressly as his own inventions. These are the "instrument with the two quadrants" (no. VI), the "instrument with the two arms" (no. VII), and the "perfect instrument" (no. X). It should not surprise us that some of these instruments turn out to be the prototypes for those Tycho Brahe constructed three hundred years later for his observatory on the island of Hven.

It seems to be certain that the knowledge of this observatory reached Europe at quite an early stage (see below, p. 35). In this connection, it is significant that the original of the celestial globe from the Maragha observatory already reached Europe before 1562 and has been preserved since then in Dresden.

Naṣīraddīn aṭ-Ṭūsī's (d. 672/1274) team
in a miniature from the *Tansūqnāma-i Īlḫānī*
MS. British Library, Or. 3222, fol. 105 a.

[4] With the exception of Mu'aiyadaddīn al-ʿUrḍī, the names are mentioned by Ruknaddīn b. Šarafaddīn al-Āmulī in the *Zīǧ-i ǧāmiʿ-i Saʿīdī*, v. A. Sayılı, *The Observatory in Islam*, p. 212.

[5] F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 10, pp. 177 ff.

2. The observatory of Istanbul

(984–88/1576–80):

About three hundred years after the foundation of the Maragha observatory, at a time when astronomical science reached the stage of creativity in Europe after 500 years of reception and assimilation, the decision was made in Istanbul in around 983/1575 or 1576 to establish an observatory, the construction of which was apparently completed before 988/1580. The idea to erect an observatory had been suggested to the Ottoman sultan Murād III by the scholar Taqīyaddin Muḥammad b. Maʿrūf ar-Raṣṣād, who came from Cairo to Istanbul. This astronomer, well-versed also in many other areas of science, planned to update the obsolete astronomical tables with the help of new observations and expected better observation results from the new large-scale instruments. He called this ambitious aim *ar-raṣad al-ǧadīd* ("new astronomical observation"). In a period which was to become the beginning of the stagnation of Arabic-Islamic sciences, he was unfortunately unable to realise his aim, due to the envy or ignorance of adversaries. This great attempt was misunderstood, erroneously or on purpose, as an undertaking to cast astrological horoscopes. Thus it came about that the sultan ordered the destruction of the observatory where the work had just begun. Its founder Taqīyaddīn survived the catastrophe by about five years. He died in 993/1585.

Statements by Ottoman historians and contemporary travellers, which do not quite agree with each other, permit the assumption that the location of the observatory founded by Taqīyaddīn was at or near the place which is now called Taksim. The condition and importance of the instruments, which are now lost, can be assessed from an extant description,[1] written down by a Turk after Taqīyaddīn's dictation; this enabled us to reconstruct the instruments.

Taqīyaddīn describes eight astronomical instruments, an astronomical clock and a special pair of dividers for drawing circles with large radii. The first six instruments were known originally either to the Greek or Arabic predecessors and then went through a process of further development, especially at the Maragha observatory. In Taqīyaddīn's description, they generally appear in large dimensions and not without additional features. Instrument Nos. VII and VIII, the "instrument with the chords" (*ālat ḏāt al-autār*) and an instrument for measuring the distances between heavenly bodies (*āla mušabbaha bi-l-manāṭiq*) seem to be listed as his own inventions. At least no. VIII and no. V, a wooden quadrant, should have been known to Tycho Brahe (see below).

It is highly probable that the news of the foundation of the Istanbul observatory, of its destruction and also of the type of its instruments reached astronomers in Europe quite quickly. We know for instance that Stephan Gerlach, the spiritual adviser to the imperial envoy in Istanbul, in his *Türckisches Tagebuch* dated 13th November 1577 reports quite extensively about the foundation of the observatory. We learn further that Gerlach had already written about it to M. Crusius with some variations on 29th September 1577, who then secured further dissemination of the report in his *Turcograecia* (Basel 1584, p. 501).[2]

[1] *Ālāt ar-raṣadīya bi-zīǧ aš-šahinšāhīya*, ed. after the MS Istanbul, Saray Hazine 45, with modern Turkish and English translation by Sevim Tekeli, in: Araştırma. Dil ve Tarih-Coğrafya Fakültesi Felsefe Araştırmaları Enstitüsü Dergisi (Ankara) 1/1963/71–122.

[2] v. J.H. Mordtmann, *Das Observatorium des Taqī ed-dīn zu Pera*, in: Der Islam (Berlin, Leipzig) 13/1923/82–96, esp. 86 (reprint in: Islamic Mathematics and Astronomy, vol. 88, Frankfurt 1998, pp. 281–295, esp. 286).

Taqīyaddīn's team after a manuscript of *Šamā'ilnāma*, Istanbul, University Library, T.Y. 1404, fol. 57a.

A more extensive report on the observatory was given by Gerlach's successor, Salomon Schweigger, who was in Istanbul from 1st January 1578 to 3rd March 1581.[3] Unfortunately, Schweigger calls Taqīyaddīn a "conjurer" and "godless simpleton" who— this is the story he spins—"had lain imprisoned for several years in Rome and had imbibed his art, and had become such a virtuoso of the heavens and a juggler of the stars" from a mathematician whose servant he had been. He had secretly asked a Jew to explain to him the Arabic translation of the writings of Ptolemy, Euclid, Proclus and "other famous astronomers". Schweigger mentions several instruments of the Istanbul observatory, among them a terrestrial and a celestial globe. Taqīyaddīn had needed, as he says, about seven years for the construction of the instruments.[4] It would lead too far to try to explain how far removed from reality Schweigger's contention is that Taqīyaddīn as a prisoner had learnt mathematics in Rome and had got the Arabic translations of the Greek works explained to him by a Jew (in any case, Taqīyaddīn's sojourn in Europe, when and wherever it is said to have taken place, is pure invention). I would only like to point out that the study of his extant works shows that we encounter in him an inventive mind and a great astronomer who knew the achievements of his predecessors quite well and who wanted to advance them a step further.

[3] J.H. Mordtmann, op. cit., p. 86 (reprint p. 285).

[4] *Ein newe Reysbeschreibung auß Teutschland Nach Constantinopel und Jerusalem*, Nuremberg, 1608 (reprint in: The Islamic World in Foreign Travel Accounts, vol. 28, Frankfurt 1995), pp. 90–91.

3. The observatory of Uranienburg on the island of Hven:

Under the patronage of the Danish king Frederick II, Tycho Brahe (1546-1602) began with the establishment of an observatory on the island of Hven (today Swedish Ven), benefiting from a recommendation of the landgrave of Hesse who had established the first observatory of Central Europe in Kassel. While studying in various European cities, Tycho Brahe had already made a name for himself through his excellent skill in making astronomical instruments. The foundation stone of the observatory was laid in August 1576. The number of instruments Tycho Brahe had manufactured between 1577 and 1597 was around eighteen. However, most of them were imitations of known instruments with minor variations or improvements. Therefore the actual number can be reduced to nine or ten. In this connection, I cite Johann Repsold:[1] "You get the impression that instruments were constructed merely in order to create work, just as after Weistritz, Tycho had poems, which he dedicated to good friends, printed to keep his paper mill busy. This way of keeping house with little sense of economy probably contributed to the fact that Tycho fell into disfavour; and after a few decades the whole splendour of Hven had sadly disappeared."

While judging Tycho Brahe's achievements, emphasis is laid on four of his instruments: his two movable azimuthal quadrants, his mural quadrant, his astronomical sextant for measuring distances, and his equatorial armillary sphere. In evaluating them, one generally proceeds from the question of how far they were already known to Greek astronomy, while possible precursors in the Arabic-Islamic area are ignored.

On this issue, the following may be mentioned: the two movable azimuthal quadrants had their predecessors among the instruments of the observatories of Maragha and Istanbul. The mural quadrant was already known in the 4th/10th century already in the Arabic-Islamic world, as we learn from al-Battānī. It appears furthermore among the large-scale instruments in the observatories of Maragha and Istanbul.

The astronomical sextant for measuring distances betrays great similarity with the *āla mušabbaha bi-l-manāṭiq* of the Istanbul observatory. Leaving aside the similarity in construction and function, what is striking is particularly the common use of two wooden sticks for propping the movable sextant up against the ground in the correct position. It is instructive that Tycho did away with the two wooden sticks in his later versions of the instrument. It is highly probable that knowledge of not merely this instrument of the Istanbul observatory reached Tycho Brahe in a short time. We have known of the use of the sextant for astronomical observation in the Arabic-Islamic world since the 4th/10th century when the astronomer al-Ḫuǧandī used the Faḫrī sextant for the precise determination of the obliquity of the ecliptic (see above, p. 25).

A sextant was also among the astronomical instruments mentioned by Ġiyāṯaddīn Ǧamšīd al-Kāšī (d. 840/1436) in his book on the description of observational instruments (see below, p. 71).

Tycho Brahe's large equatorial armillary sphere, which he calls *armillae aequatoriae maximae* in his book,[2] is essentially "quite a strange simplification of the armillary instrument. What are retained are just the circle of declension and half of the hour circle."[3]

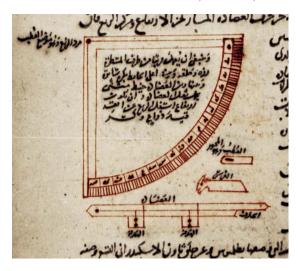
[**37**] The result of the comparing the instruments constructed by Tycho Brahe between 1577 and 1597 for the observatory of Hven with those of the two observatories of Maragha (1260-1270) and Istanbul (1576-1580) may be summed up here: Basically, the instruments of Hven are further reproductions of those models which we know from the two

[1] *Zur Geschichte der astronomischen Meßwerkzeuge von Purbach bis Reichenbach 1450–1830*, Leipzig 1908, p. 29.

[2] *Tycho Brahé's Description of his Instruments and Scientific Work as given in Astronomiæ instauratæ mechanica (Wandesburgi 1598)*. Translated and Edited by Hans Roeder, Elis Strömgren and Bengt Strömgren, Copenhagen 1946, pp. 64–67.

[3] J.A. Repsold, *Astronomische Meßwerkzeuge*, p. 27.

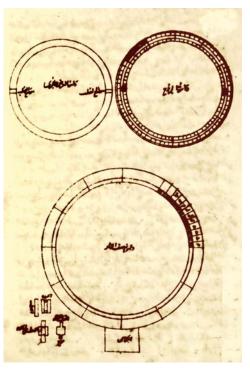
observatories of Maragha and Istanbul. The striving for large dimensions for the sake of greater precision in measurements is characteristic of the instruments of all three observatories. One difference is particularly striking in this comparison, namely the exaggerated ornamentations and engravings which are displayed in Tycho Brahe's instruments[4] in contrast to the simplicity of the models from Maragha and Istanbul, and which were certainly not advantageous when using the instruments.

A common feature in method of observation of Tycho Brahe and Taqīyaddīn is that they take into account time as an element of its own with the help of a portable clock.

[4] v. also Sevim Tekeli, *Nasirüddin, Takiyüddin ve Tycho Brahé'nin rasat aletlerinin mukayesi*, in: Ankara Üniversitesi Dil ve Tarih-Coğrafya Fakültesi Dergisi 16/1958/301–393.

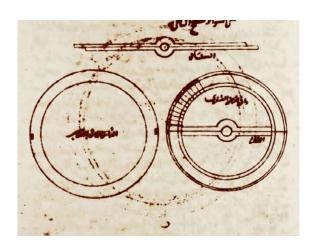
THE INSTRUMENTS OF THE MARĀĠA OBSERVATORY

I. Mural Quadrant

Fig. from al-ʿUrḍī's Book of Instruments, MS Istanbul, Ahmet III, 3329.

In his *Risāla fī Kaifīyat al-arṣād wa-mā yuḥtāğu ilā ʿilmihī* (ms. İstanbul, Ahmet III, 3329) describes a quadrant attached to the wall (*labina* or *rubʿ*) as the first of the above mentioned astronomical instruments that were constructed around 1260 for the Maragha observatory. An alidade is affixed at the centre of the circle that defines the quadrant, the length of which corresponds to the radius of the circle. The length of the original radius of the quadrant constructed from teak wood was ca. 2.5 m. The mural quadrant served for determining the solar altitude, the obliquity of the ecliptic and the latitude of the place of observation.

H. Seemann, *Die Instrumente der Sternwarte zu Marâgha*, in: Sitzungsberichte der Physik.–med. Sozietät zu Erlangen 60/1928/15–126, esp. pp. 28–33 (reprint in: Islamic Mathematics and Astronomy, vol. 51, pp. 81–192, esp. pp. 94–99); Sevim Tekeli, *Al-Urdî'nin ‹Risalet-ün Fi Keyfiyet-il Ersad› Adlı Makalesi*, in: Araştırma (Ankara) 8/1970/1–169, esp. pp. 103–108.

Our model:
Wood, laminated, marble base.
Height: 35 cm.
Brass quadrant, etched, in a teak wood frame; rotating alidade.
Inventory No. A 4.27

Fig. from al-ʿUrḍī's Book of Instruments, MS Istanbul, Ahmet III, 3329.

Our model:
Brass, engraved.
Diameter 50 cm.
Scale ca. 1:7.
(Inventory No. A 4.18)

II. Armillary Sphere

The armillary sphere (*ḏāt al-ḥalaq*) is mentioned in second place by Muʾaiyadaddīn al-ʿUrḍī in his book on the astronomical instruments of the Maragha observatory. It served generally for determining the star coordinates, but it was also used for solving other astronomical problems. The common form of the armillary sphere combines in itself the three systems of reference: horizontal (altitude and azimuth), equatorial (right ascension and declination) and ecliptic (celestial latitude and longitude). The model described by Muʾaiyadaddīn al-ʿUrḍī [**40**] consisted of five rings.

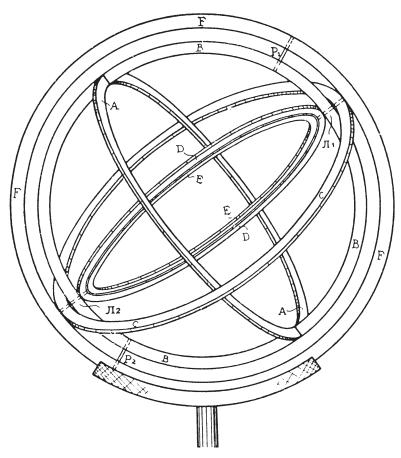



Fig. from H. Seemann, *Die Instrumente der Sternwarte zu Marâgha*, pp. 33–53, esp. p. 35 (reprint, op. cit., pp. 99–119, esp. p. 101); for the Arabic text v. S. Tekeli, *Al-Urdî'nin ‹Risalet-ün Fi Keyfiyet-il Ersad› adlı Makalesi*, pp. 108–124.

He thought it unnecessary to increase the number of rings, as for instance to six by Ptolemy or to nine by Theon. His instrument was constructed as an ecliptic armillary sphere for observations in the ecliptic system.

The outermost and also the largest ring F (see annexed figure) represents the meridian circle. This is followed by the large latitude ring B which is marked by a division of 4 times 90° = 360° and which can be moved downwards or upwards with the help of pins 1 and 2. Rings C and D are joined with one another at the division of 90°. Ring A represents the ecliptic circle, while ring B, called *al-ḥalqa al-ḥāmila* ("the supporting circle") corresponds to the solstitial colure. The ecliptic ring is divided into 12 signs of the zodiac, each of 30°, and can be rotated with the help of the "supporting" ring around the two pins of the axis. D is the smaller latitude ring. Like ring B, this too is divided into 4 times 90°, beginning at the ecliptic. "Along this division, the pointers at the ends of the alidade glide, which is pivoted within ring D so that it rotates in the plane of the former."

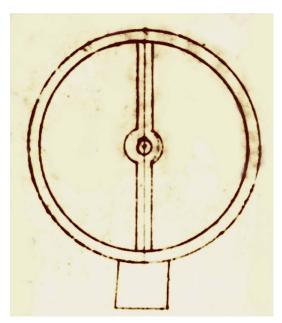



Fig. from al-ʿUrḍī's Book of Instruments,
MS Istanbul, Ahmet III, 3329.

Our model:
Brass, engraved.
Pillar of hard wood.
Diameter: 45 cm,
scale ca. 1: 6.
Adjustable brass pointer with sight.
(Inventory No. A 4.17)

III. Solstitial Armilla

This instrument, which is traced back to Ptolemy by Muʾaiyadaddīn al-ʿUrḍī, served for determining the obliquity of the ecliptic (*āla li-maʿrifat mail falak al-burūǧ*). "A ring of 2.5 m inner diameter is set up in the plane of the meridian, attached to a pillar. There is a vertical bar inside the ring for reinforcement; at the centre of this vertical bar, the alidade is pivoted, its two ends gliding on a division, which is inscribed on one of the flat surfaces of the ring, and from which the altitude of solar culmination is read. In the original form devised by Ptolemy, instead of the alidade, a ring with sights was attached in the inner side of the meridian ring." With this instrument it was possible, as Muʾaiyadaddīn says, to ascertain the altitude of the pole through observation of the upper and lower culmination positions of circumpolar stars. This method of determining the altitude of the pole with a special instrument, which was known in Europe under the name of Jacob's staff, was the basic method of navigation in the Indian Ocean.

H. Seemann, *Die Instrumente der Sternwarte zu Marâgha*, op. cit., p. 53 (reprint, op. cit., p. 119); for the Arabic text v. S. Tekeli, *Al-Urdî'nin ‹Risalet-ün Fi Keyfiyet-il Ersad› Adlı Makalesi*, pp. 124–127.

Our model:
Brass, etched,
with an alidade that can be
rotated along the radius,
diameter: 43 cm.
Wooden pillar, sandstone lamination,
marble base.
Total height: 165 cm.
(Inventory No. A 4.28)

IV. Equinotial Armilla

This instrument, already mentioned by Ptolemy, served to determine the Sun's entry into the equinoxes. The version described by Mu'aiyadaddīn al-ʿUrḍī from the stage of development known to him (*ḥalqat al-istiwāʾ*) consisted of a vertical meridian ring with a scale and a ring attached to it at a right angle, called equator ring. The latter is aligned to the plane of the equator. The instrument is installed according to the ascertained latitude of the place of observation, which is equal to the length of the distance of the celestial equator from the zenith of the observer.

H. Seemann, *Die Instrumente der Sternwarte zu Marâgha*, op. cit., pp. 57–61 (reprint, op. cit., pp. 123–127); for the Arabic text v. S. Tekeli, *Al-Urdî'nin ‹Risalet-ün Fi Keyfiyet-il Ersad› Adlı Makalesi*, pp. 127–129

Fig. from al-ʿUrḍī's Book of Instruments, MS Istanbul, Ahmet III, 3329.

V.
The Instrument with the Movable Sight

The fifth instrument which Muʾaiyadaddīn al-ʿUrḍī describes in his book, the "instrument with the two holes" (*al-āla ḏāt aṯ-ṯuqbatain*), served for measuring the apparent diameters of the Sun and the Moon and for their observation. "For this there are two discs added to the instrument which are equipped with holes corresponding to the apparent diameters of the Sun or the Moon. By holding the discs in front of the movable sight, that part of the Sun or the Moon which is not obscured can be blocked and thus the size of the eclipsed part measured."
The measuring apparatus of the original with its movable sights had a length of ca. 230 cm.

Our model:
walnut, table diameter: 65 cm.
Observation rail 110 cm,
can be rotated horizontally, and adjusted vertically around the central axis.
Millimetre scale engraved.
Copper sights.
(Inventory No. A 4.16)

H. Seemann, *Die Instrumente der Sternwarte zu Marâgha*, op. cit., p. 63 (reprint, op. cit., pp. 129); for the Arabic text v. S. Tekeli, *Al-Urdî'nin ‹Risalet-ün Fi Keyfiyet-il Ersad› Adlı Makalesi*, pp. 129–135.

Our model:
Scale ca. 1:10.
Diameter 50 cm.
Two brass quadrants which can be rotated around the axis.
With division in degrees and movable pointers with sights.
(Inventory No. A 4.15)

VI.
The Instrument with the Two Quadrants

The "instrument with the two quadrants" (*al-āla ḏāt ar-rubʿain*) was one of the characteristic instruments of the Maragha observatory. It was described at length by Muʾaiyadaddīn, who stresses that it belongs to those instruments which he himself developed. The instrument was used for measuring the altitude and azimuth of stars. Its special advantage lay in the possibility that two observers could simultaneously take their observations. Hugo Seemann was the first to reconstruct the instrument.

H. Seemann, *Die Instrumente der Sternwarte zu Marâgha*, op. cit., pp. 72-81 (reprint, op. cit., pp. 138-147); for the Arabic text v. S. Tekeli, *Al-Urdî'nin ‹Risalet-ün Fi Keyfiyet-il Ersad› Adlı Makalesi*, pp. 135-145.

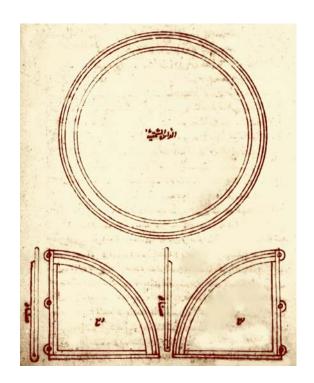



Fig. from al-ʿUrḍī's Book of Instruments, MS Istanbul, Ahmet III, 3329.

Our model:
Laminated wood, marble base.
Brass quadrant, etched;
radius: 40 cm.
Teak wood rulers, vertically
movable between two pillars,
height: 64 cm.
Brass metric scale
on the chord ruler.
(Inventory No. A 4.26)

VII.
The Instrument with the Two Arms

The "instrument with the two arms" (*al-āla ḏāt aš-šuʿbatain*) is one of the devices that Muʾaiyadaddīn al-ʿUrḍī himself developed. It was used for determining of the culmination altitudes and was combined with a mural quadrant (above, no. I). The instrument, aligned to the meridian, had a height of ca. 3 m. A vertical ruler moves with a cross-piece connected to it. The ruler carries a sight, the cross-piece, a graduated scale that serves to determine the size of the angle of the celestial body aligned through the sight on the ruler. From the ratio of the constant height of the instrument to the length that was read off the cross-piece, the size of the angle is found with the help of a special table. The angle of the culmination altitude to be measured is found with the help of the mural quadrant. Attached to the wall that supports the mural quadrant there are also two pulleys over which two ropes run that serve for raising and lowering the two rulers.

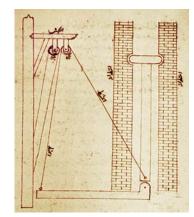



Fig. from al-ʿUrḍī's Book of Instruments, MS Istanbul, Ahmet III, 3329.

H. Seemann, *Die Instrumente der Sternwarte zu Marâgha*, pp. 81–87 (reprint, pp. 147–153); for the Arabic text v. S. Tekeli, *Al-Urdî'nin Risalet…*, pp. 145–149. For an abridged French translation v. A. Jourdain, *Mémoire sur les instruments employés à l'observatoire de Méragha,* pp. 55-59 (reprint, pp. 107–111); v. L.-A. Sédillot, *Mémoire sur les instruments astronomiques des Arabes*, p. 200.

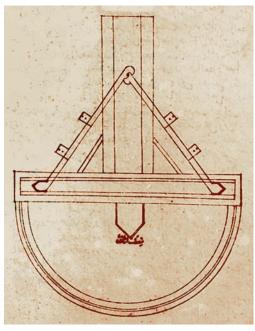
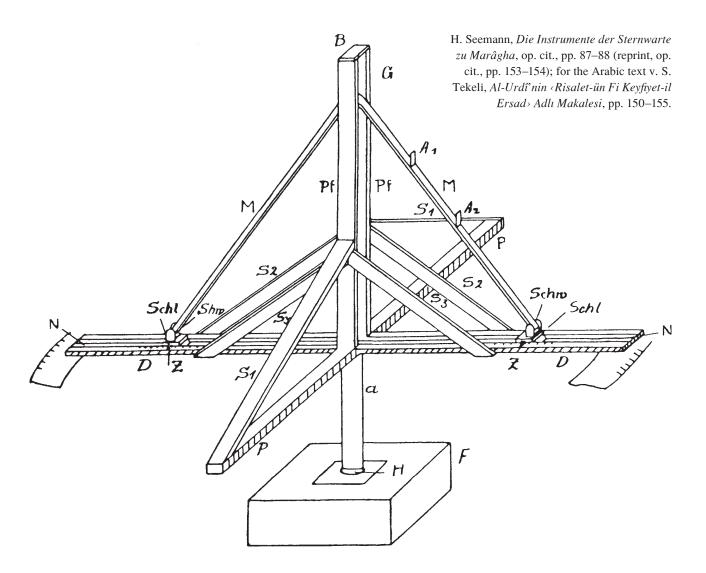
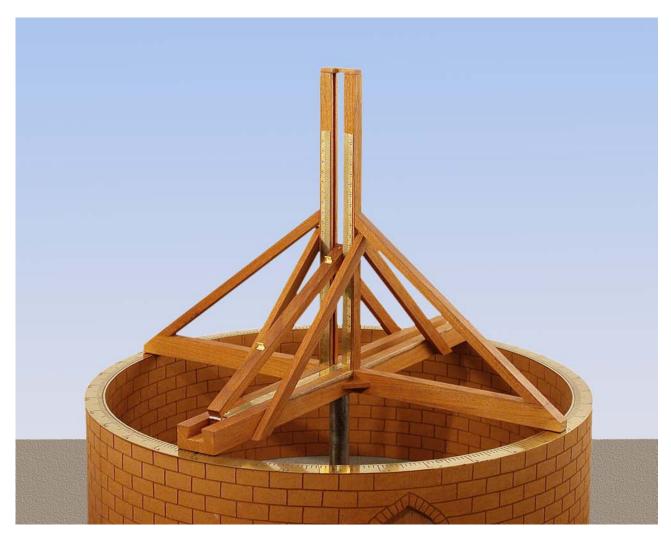
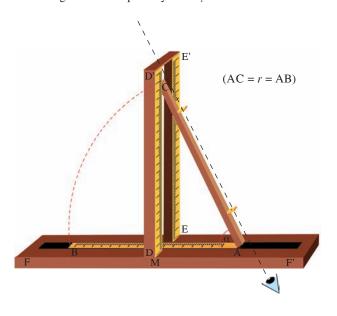
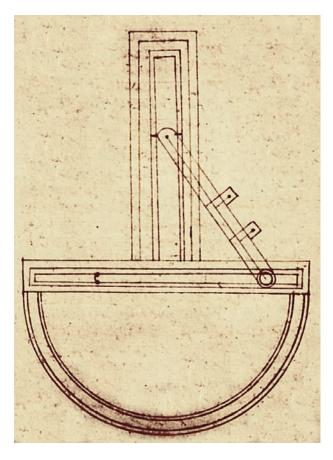



Fig. from al-ʿUrḍī's Book of Instruments,
MS Istanbul, Ahmet III, 3329.

Our model:
Scale ca. 1:10.
Diameter 50 cm.
Attachment of stained hard wood,
rotating around a metal axis
with arms that can be adjusted on both sides.
Brass scale.
(Inventory No. A 4.07)

VIII.
The Instrument for Determinining Altitudes and Azimuts

Among the instruments manufactured for the Maragha observatory, Muʾaiyadaddīn al-ʿUrḍī also mentions an "apparatus with sine and azimuth" (*al-āla ḏāt al-ǧaib wa-s-samt*). Whether he himself invented this instrument is not stated clearly. In Europe, it was constructed and described by Tycho Brahe as *Parallaticum aliud sive regulae tam altitudines quam azimutha expedientes* (see below, p. 62).
The observation chamber consists of a circular wall on which a circular scale is affixed with graduations in degrees and further subdivisions."The measuring device proper consists of two rulers, the so-called measuring rulers, which are connected to each other by a hinge like the arms of a pair of dividers. The apex of this pair of dividers can be moved vertically up and down in a groove. Then the free ends of the dividers, to each of which a coaster is connected with a hinge, slide symmetrically towards each other in a horizontal direction in a dovetailed groove [**47**] cut into the upper surface of a horizontal beam, the so-called diameter.""The vertical groove in which the apex of the dividers moves up and down is formed by two vertical posts in which groves are cut length-wise for this purpose; these

are attached to both sides of the diameter beam at its centre…The diameter and the transverse beam form a horizontal cross. The whole apparatus is pivoted to a vertical iron axis erected at the centre of the circular wall; the iron axis is inserted in a foundation slab of stone so that it can rotate and is surrounded by a wooden box. To the upper end of the axis, the centre of the above-mentioned cross is attached, on which the measuring apparatus rests. The instrument can be rotated around the iron axis; then the ends of the diameter, which serve the purpose of indicators, move on the divisions of the horizontal ring which lies on the circular wall.""On the upper surfaces of the two measuring rulers, two sights each are attached, through which it is possible to sight the heavenly bodies and to determine their sin β. The latter is done as follows: the diameter is furnished with an appropriate scale of divisions on both sides of the groove and on both sides from its centre. The distance which the end of the measuring ruler cuts off in this division, divided by the length of a measuring ruler, produces the sine of the complement of the angle of elevation (α). At the same time it is possible to ascertain the azimuth at that division of the horizontal ring where the corresponding end of the diameter rests."

H. Seemann, *Die Instrumente der Sternwarte zu Marâgha*, op. cit., pp. 87–88 (reprint, op. cit., pp. 153–154); for the Arabic text v. S. Tekeli, *Al-Urdī'nin ‹Risalet-ün Fi Keyfiyet-il Ersad› Adlı Makalesi*, pp. 150–155.

IX.
The Instrument for Determining the Sine upon a Vertical Scale

Our model:
Scale ca. 1:10.
Diameter 40 cm.
Attachment of stained hard wood, rotating around a metal axis with a pair of dividers moving in a groove.
Brass scales.
(Inventory No. A 4.30)

A second version of the preceding instrument, which Mu’aiyadaddīn al-ʿUrḍī constructed for the Maragha observatory, is the “instrument for sine measurement and with a vertical scale” (*al-āla ḏāt al-ğuyūb wa-s-sahm*). Except for the measuring device, it is fully identical to the preceding one. The purpose of the changed measuring device is that here the elevation of the angle of the sighted celestial body is found immediately as the sine, while the observation result with the previous version had to be calculated through the complement of the angle of elevation. This instrument also permits the measurement of the azimuth through its pivoting.

Fig. from al-ʿUrḍī's Book of Instruments, MS Istanbul, Ahmet III, 3329.

Diagram of the function of the instrument according to the description by al-ʿUrḍī.

At the centre of M of the diameter FF' stand two vertical guide posts DD' and EE'. A pair of dividers, the arms of which correspond to half the diameter, is inserted in a groove on the line FF', and into the recess between the two guide posts in such a way that the two points B and C can be moved with the help of a hinge at the apex A. The arm AC, the hypotenuse, carries the two sights, the sine of the altitude is found by the ratio of the length measured at the guide posts, which also have a scale, to the arm AC. The scales each correspond to half the diameter and are divided into sixty parts of the scale, and further subdivisions of the same. Additionally, the second arm (AB) is equipped with a horizontal scale for measuring the versed sine of the angle of elevation of the observed heavenly body:

$$\sin \alpha = MC/AC$$
$$\sin vers\, \alpha = AM/AC = 1 - \sin \alpha.$$

H. Seemann, *Die Instrumente der Sternwarte zu Marâgha*, op. cit., pp. 92-96 (reprint, op. cit., pp. 158-162); for the Arabic text v. S. Tekeli, *Al-Urdî'nin ‹Risalet-ün Fi Keyfiyet-il Ersad› Adlı Makalesi*, pp. 156-158.

X.
The Perfect Instrument

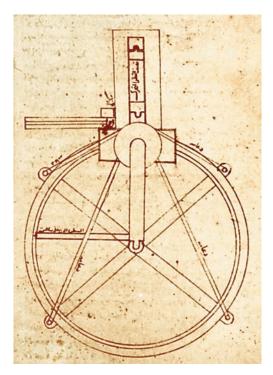



Fig. from al-ʿUrḍī's Book of Instruments, MS Istanbul, Ahmet III, 3329.

The "perfect instrument" (*al-āla al-kāmila*) is one of the instruments which Muʾaiyadaddīn al-ʿUrḍī mentions as his own invention. He says that he constructed it in 650/1252 for the ruler of Ḥimṣ (Syria), al-Malik al-Manṣūr.[1] "The measuring device proper rests on a stand which corresponds to that of the instrument discussed under no. V ('with the movable sight'), except that the cross, which serves as the base, is surrounded by a graduated ring. Through the hole bored at the centre of the circular plate, which is supported by stakes, a vertical rotating pillar is inserted, to the upper end of which a squared rectangular is affixed."

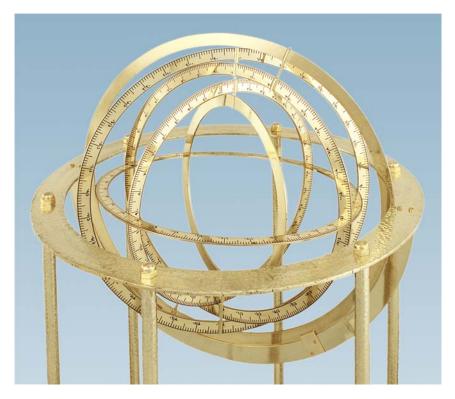
"On this attachment is mounted the measuring device proper. Like the instrument discussed under VII ('with the two arms'), it consists of a so-called altitude ruler, 2.25 m long, which is pivoted between the upper ends of two equally long pillars that are mounted vertically on the attachment, and equipped with two sights. A second ruler, the so-called chord ruler, which is one and a half times [**51**] as long as the altitude ruler, is pivoted to the lower end of one of the vertical pillars. It is cut in

[1] If the name al-Malik al-Manṣūr is correct (r. 637/1239 - 644/1246), then there must be a mistake with the date mentioned. If the date is correct, then the ruler referred to must be the son of the former, al-Malik al-Ašraf Mūsā b. al-Malik al-Manṣūr Ibrāhīm b. al-Malik al-Muǧāhid Šīrkūya (r. 644/1246 - 661/1263).

such a way that the two longitudinal surfaces facing each other of the two rulers touch each other."
"The chord ruler is equipped with a corresponding scale as in the instrument discussed under VII; in the same manner, when the heavenly body is sighted, the chord of the complement of the angle of elevation is read from this scale."
"The instrument is positioned in accordance with the four cardinal points and is made fast to the ground. Like the instrument discussed under VII, it is a parallactic ruler, with an additional feature, viz. by rotating the vertical turning pillar it can be adjusted for any desired azimuth. Its area of application is correspondingly wider; it can serve for the solution of a number of astronomical problems which arise from the determination of the altitude and azimuth of a heavenly body."

H. Seemann, *Die Instrumente der Sternwarte zu Marâgha*, op. cit., pp. 96-104 (reprint, op. cit., pp. 162-170); for the Arabic text v. S. Tekeli, *Al-Urdî'nin ‹Risalet-ün Fi Keyfiyet-il Ersad› Adlı Makalesi*, pp. 159-165.

Our model:
Scale: almost 1:2.
Hard wood, stained.
Total height: 220 cm.
Chord, ruler, length: 167 cm, with brass metric scale.
Altitude ruler with two brass sights.
The undercarriage, on which the two rulers are mounted, is pivoted to the pedestal where a brass pointer shows the position on a 360° scale, which is likewise made of brass.
(Inventory No. A 4.29)

XI.

Celestial Globe

It is indeed very fortunate that the celestial globe of the Maragha observatory has come down to us. The magnificent globe, crafted in 1279 by Muḥammad, a son of Mu'aiyadaddīn al-ʿUrḍī, reached Dresden in 1562, and there it has been preserved for 250 years in the Mathem atisch-Physikalischer Salon. Its importance was already pointed out in the 18th century by Carsten Niebuhr. "The Dresden globe consists of a sphere with a diameter of 144 mm, made of bronze like the rings. Engraved on the sphere are: the ecliptic and the equator with divisions in degrees, twelve latitude circles for the demarcation of the zones of the zodiac signs, the outlines and shading of the constellation figures, the names of the constellations, of the signs of the zodiac and of the individual stars, the star points of different magnitudes, the positions of the poles of the ecliptic and those of the equator, and the maker's name. At the positions of the poles themselves small round holes have been bored for inserting the axis pins. Inlaid are: the ecliptic with gold; the equator, the star points, the names of the constellations and the maker's name with silver; the names of the zodiac signs alternately with gold and silver. These inlays, as also the engravings, show a very skilled hand. The horizontal ring, the upper half of the meridian ring and the altitude quadrants contain divisions in degrees. The lower half of the meridian ring which is under the horizon ring and is attached to it, is equipped with small circular holes, each 5 degrees apart from the other, so that the globe can be tilted by inserting the axis pin for different pole elevations."[1]

Our replica has the same dimensions as the original. Globe: brass, silver inlay. Brass stand, while the original rests on a wooden stand made in Europe in the 17th century.
(Inventory No. A 1.03)

[1] Adolph Drechsler, *Der Arabische Himmelsglobus des Mohammed ben Muyîd el-'Ordhi vom Jahre 1279 im Mathematisch-physikalischen Salon zu Dresden*, 2nd ed., Dresden 1922, 19 pp., 8 pl., esp. p. 9 (reprint in: Islamic Mathematics and Astronomy, vol. 50, Frankfurt 1998, pp. 261–289, esp. p. 271).

Additional literature: Wilhelm Sigismund Beigel, *Nachricht von einer* Arabischen Himmelskugel mit Kufischer Schrift, *welche im Curfürstl. mathematischen Salon zu Dresden aufbewahrt wird*, in: Astronomisches Jahrbuch für das Jahr 1808 (Berlin), pp. 97–110 (reprint ibid., pp. 81–94); Aimable Jourdain, *Mémoire sur les Instrumens employés à l'Observatoire de Méragah*, in: Magasin encyclopédique (Paris) 6/1809/43–101 (reprint ibid., pp. 95–153); Karl Heinz Schier, *Bericht über den arabischen Himmelsglobus im Königl. Sächs. mathematischen Salon zu Dresden*, in: Schier, *Globus coelestis arabicus…*, Leipzig 1865, Additamentum pp. 65–71 (reprint ibid., pp. 154–160); Ernst Kühnel, *Der arabische Globus im Mathematisch–Physikalischen Salon zu Dresden*, in: Mitteilungen aus den Sächsischen Kunstsammlungen (Leipzig) 2/1911/16–23 (reprint ibid., pp. 252–259).

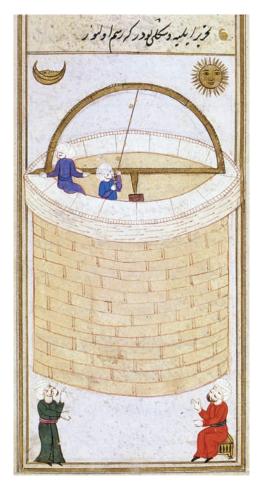
THE INSTRUMENTS OF THE OBSERVATORY OF İSTANBUL (984–88/1576–80)

Our model:
Brass, etched,
Diameter: 50 cm.
(Inventory No. A 4.09)

I. Armillary Sphere

In the book on the instruments of the Istanbul observatory, the armillary sphere, the "apparatus with the rings" (*ḏāt al-ḥalaq*), occupies the first place. For the size of the horizontal ring, which functions as the support, a diameter of at least 4 metres is recommended. Apart from the horizontal ring, the instrument contains six more rings which serve primarily for the determination of the fixed star coordinates. According to size they are 1. the meridian ring which is fixed immovably in north-south direction, 2. the movable large meridian ring, 3. the ecliptic ring, 4. the ring of the colure (Arabic *ḥāmila*, the "support"), 5. the small meridian ring which passes through the poles of the ecliptic—the last two intersect at right angles and are firmly attached to each other—and 6. the latitude ring equipped with two sights. The horizontal ring which supports the whole complex of rings is connected by six rods to a ring of the same size which serves as the base. According to a statement in the book of instruments, five persons were required to work with this observation apparatus.

S. Tekeli, *Âlât-i raṣadiye li zîc-i şehinşahiye*, in: Araştırma (Ankara), 1/1963/79–80, 105–107.

Extrait du ms. İstanbul Saray, Hazine 452.

From MS Saray, Hazine 452.

Our model:
Scale ca. 1:10.
Wood, laminated; 50 × 50 × 80 cm.
2 quadrants and pointers
with sights of brass, etched.
(Inventory No. A 4.13)

II. Mural Quadrant

For determining the daily culmination of the Sun and of the meridional altitudes of the planets, a mural quadrant (labina) in the plane of the meridian was also constructed among the instruments of the Istanbul observatory. Its measurements were roughly 7 × 7 m.

S. Tekeli, *Âlât-i raṣadiye*, op. cit., pp. 80, 108–109.

From MS Saray, Hazine 452.

Our model:
Scale ca. 1: 10.
Diameter 50 cm.
Attachment of brass with graduations of degrees engraved on both sides, rotating around the axis.
Pointer with sight, adjustable around the centre of the semicircle.
(Inventory No. A 4.11)

III.

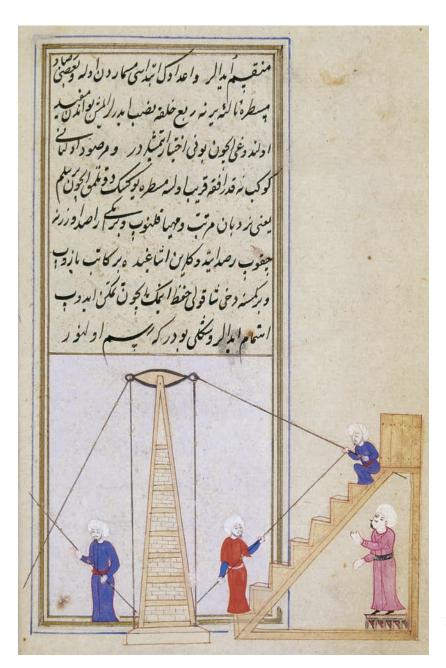
Apparatus for Determing the height of Celestial Bodies and their Azimuths

This apparatus is mentioned as the third of the instruments constructed between 1575 and 1580 for the Istanbul observatory under the direction of Taqīyaddīn al-Miṣrī. The book of instruments of the observatory mentions that Taqīyaddīn followed the example of the instrument of a Damascene astronomer which had already been imitated for the Maragha observatory and had been used by the well-known astronomer Ibn aš-Šāṭir (8th/14th c.). There is no doubt that the "Damascene astronomer" stands for Muʾaiyadaddīn al-ʿUrḍī (above, p. 38 fff). The astronomers in Istanbul replaced the double quadrant of the model with a semicircle.

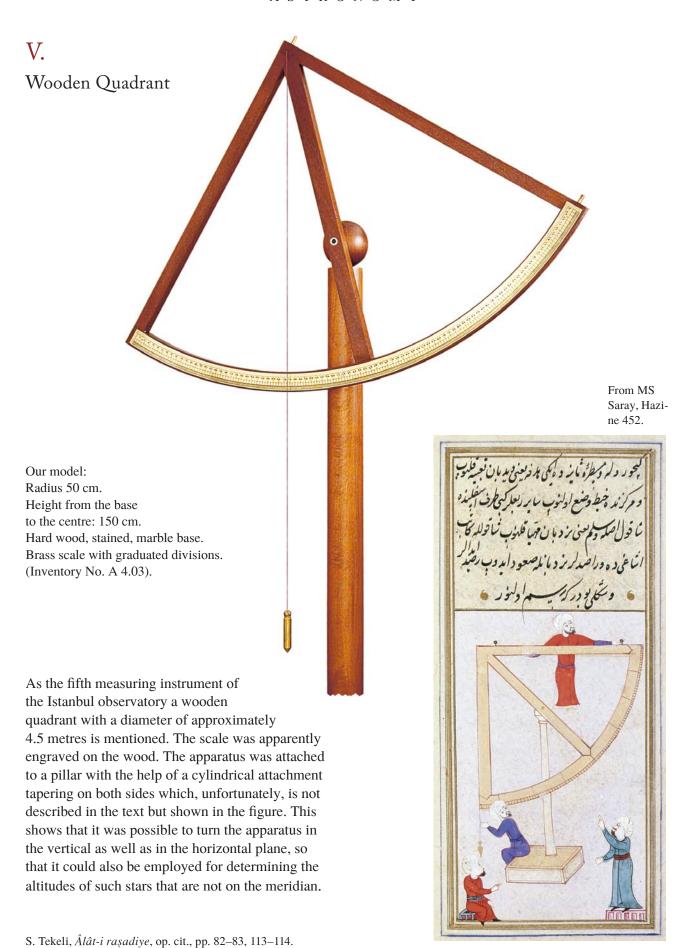
The cylindrical structure that carried the measuring apparatus was approximately 6 metres high. Its diameter is not mentioned, but should have been about 5 metres, judging from the relation to the height of the building.

The "instrument for azimuth and elevation" (*ālat ḏāt as-samt wa-l-irtifāʿ*) served, as its name indicates, for determining altitudes and azimuths. In this connection, the book of instruments emphasises, above all, the observation of "the difficult positions of Mercury and Venus".

S. Tekeli, *Âlât-i raṣadiye*, op. cit., pp. 80–81, 109–110.

Our model:
Diameter 60 cm.
Base plate: 76 × 76 cm.
(Inventory No. A 4.31)

IV.
The Instrument with the Two Arms

The observational apparatus mentioned in the fourth place in the book of instruments of the Istanbul observatory is related to Ptolemy's parallactic ruler. But there can be no doubt that Taqīyaddīn and his assistants followed the more advanced model of the Maragha observatory, the "instrument with the two arms" (*al-āla ḏāt aš-šuʿbatain*) (see above, no. VII of the Maragha instruments). Yet the range of tasks and also the dimensions and the arrangement of the structure differed substantially from those of the apparatus at the Maragha observatory.

While the chord ruler of Maragha with its construction was a measuring apparatus that rotated in the plane of the meridian and, consequently, served only for the determination of culmination heights of the Sun and the Moon during their transit of the meridian, [**57**] the apparatus at the Istanbul observatory allowed the observation of the position of the heavenly bodies by day and night in all directions, besides the determination of the altitudes of the Sun and the Moon and the measuring of their parallax. Moreover, like all other instruments at Istanbul, this

From MS Saray, Hazine 452.

instrument was twice as large as its predecessor at the Maragha observatory.

From the description and the illustration in the text it is obvious that the two chord rulers, together with the two transverse rulers and the two vertical rulers, were pivoted in such a way that the observation of the firmament above the horizontal plane in all directions was possible. A staircase was used for observing heavenly bodies with low elevations. It appears that the room with the steps running around must have been shaped like an amphitheatre. It is pointed out that the observations had to be done by two persons and that the results of the measurements had to be written down by a third person standing below.

S. Tekeli, *Âlât-i raṣadiye*, o. cit., pp. 81–82, 111–113.

V.
Wooden Quadrant

Our model:
Radius 50 cm.
Height from the base
to the centre: 150 cm.
Hard wood, stained, marble base.
Brass scale with graduated divisions.
(Inventory No. A 4.03).

From MS
Saray, Hazi-
ne 452.

As the fifth measuring instrument of the Istanbul observatory a wooden quadrant with a diameter of approximately 4.5 metres is mentioned. The scale was apparently engraved on the wood. The apparatus was attached to a pillar with the help of a cylindrical attachment tapering on both sides which, unfortunately, is not described in the text but shown in the figure. This shows that it was possible to turn the apparatus in the vertical as well as in the horizontal plane, so that it could also be employed for determining the altitudes of such stars that are not on the meridian.

S. Tekeli, *Âlât-i raṣadiye*, op. cit., pp. 82–83, 113–114.

VI.

Parallactic Ruler

Our model:
Hard wood, stained.
Length of the sight 80 cm.
Brass scale with metric divisions of length.
(Inventory No. A 4.05)

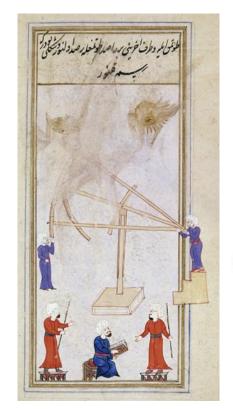
The sixth instrument mentioned in the book of instruments of the Istanbul observatory is the parallactic ruler, described already by Ptolemy, called in Arabic "that with the two holes" (*ḏāt aṯ-ṯuqbatain*). Muʾaiyadaddīn al-ʿUrḍī declared the ruler as described by Ptolemy as "highly imperfect" in three respects (see H. Seemann, *Die Instrumente der Sternwarte zu Marâgha*, op. cit., pp. 104-107, esp. p. 106; reprint, op. cit., pp. 170-173, esp. p. 172). The Istanbul astronomers do not mention Muʾaiyadaddīn al-ʿUrḍī's reservations. The description in their book of instruments is, unfortunately, too brief. It is assumed that the reader knows many details that remain unmentioned. With the prescribed length of the two rulers, which are connected to each other, of 12 measuring ells, ca. 6 m, one of the three reservations of al-ʿUrḍī is easily removed. The ruler, which was movable towards the west and the east in the construction of the Istanbul observatory, served not only for measuring the lunar parallax on the meridian but, with its long arms, also for measuring the altitudes of heavenly bodies as precisely as possible.

S. Tekeli, *Âlât-i raṣadiye*, op. cit., p. 83, 115.

From MS Saray, Hazine 452.

VII.

The Instrument with the Chords

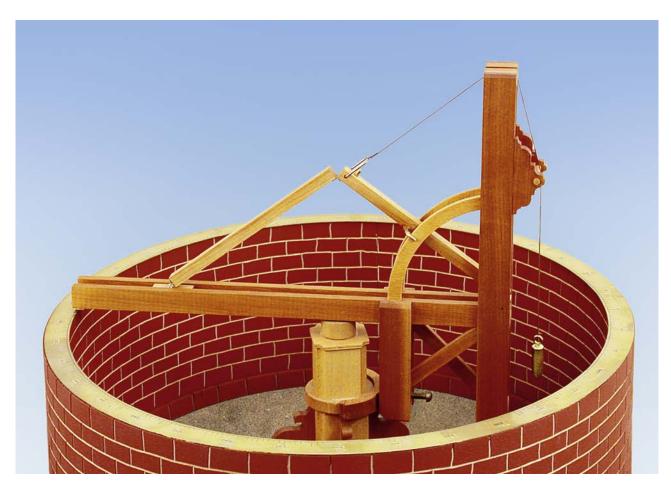
Our model:
Width: 50 cm.
Height: 61 cm.
Hard wood, glazed.
Brass plummets on ropes.
(Inventory No. A 4.32)

From MS Saray, Hazine 452.

With the "instrument with the chords" (*al-āla ḏāt al-autār*), which is listed as the seventh in the book of instruments of the Istanbul observatory, Taqīyaddīn wanted to replace the equinoctial armilla of the predecessors (see no. IV of the Maragha instruments). The observation of the Sun at the equinoxes was not to be done any more with the equator ring. Taqīyaddīn replaced the equator ring and the horizontal plane by a rectangular frame set up horizontally on four feet with two pillars of the same length standing on its southern rim. The pillars were connected with one another and with the northern edge of the frame by ropes which served as chords. The pillars as the height of a triangle and the edges next to them were so aligned that the sine of the angle corresponded to the angle of solar altitude at equinoxes at the place of observation.
In the too brief description, the measurements are not given. But, considering Taqīyaddīn's fundamental principle of achieving more precise results than the predecessors with the largest possible measuring apparatus with the finest possible divisions, and considering the stature of the persons in the picture of the manuscript, it may be assumed that the instrument had a length of ca. 3 m, a width of ca. 2.5 m and a height of ca. 3.5 m.

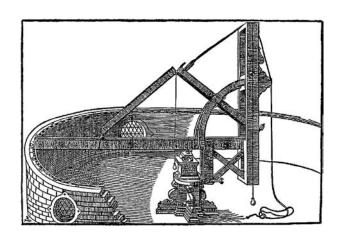
S. Tekeli, *Âlât-i raṣadiye*, op. cit., pp. 83, 115–116.

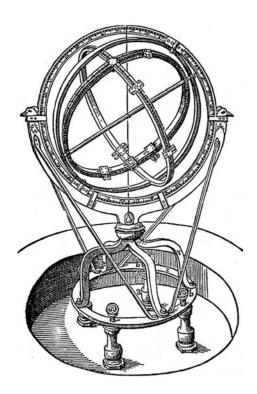
From
MS Saray,
Hazine 452.

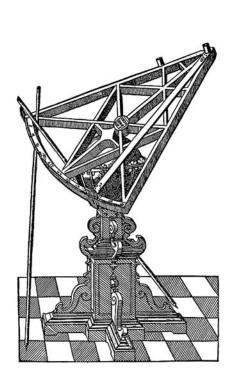
Our model:
Radius 80 cm.
Hard wood, stained.
Marble base.
Height from base to centre 150 cm.
Brass scale with divisions
in degrees and minutes.
(Inventory No. A 4.01)

VIII.

Instrument for the Measurement of Distances between Heavenly Bodies

In the instrument book of the Istanbul observatory, a measuring apparatus is mentioned in eighth place under the name of *al-āla al-mušabbaha bi-l-manāṭiq*, the inventor of which is possibly Taqīyaddīn. It was primarily meant for determining the radius of Venus. On closer inspection it turns out that the instrument, both according to its function and its construction, is an advanced model of the "instrument with the two arms" (above, no. IV). Since it is constructed in such a way that it moves easily, it has the ability to measure in three dimensions. The scale in the form of a bow (apparently divided into 60°) is connected at its upper end and in the centre with the two wooden arms which form an acute angle. An additional arm, movable vertically, which is attached with a pin in the vertex of the supporting arms and whose farthest end can be moved up and down in a groove of the scale, serves to measure vertical distances. Furthermore, a horizontal scale is attached with a hinge in the vertex of the two arms and can be moved back and forth through a joint on the lower arm. This scale serves to measure distances in the horizontal plane. The wooden sticks leaning against the instrument are there to prop it up against the ground so that the result of the observation can be read off unimpaired.

S. Tekeli, *Âlât-i raṣadiye*, pp. 83, 116–118; idem, *Nasirüddin, Takiyüddin ve Tycho Brahé'nin rasat aletlerinin mukayesesi*, pp. 360–363.

I.
Instrument for Measuring Altitudes and Azimuths

Our model:Scale 1:10. Diameter 50 cm.
Attachment of wood, movable around the axis.
The arm can be moved easily with the counterweight.
Scale of brass with divisions in degrees
(Inventory No. A 4.08)

Tycho Brahe called it *Parallaticum aliud, sive regulae tam altitudines quam azimutha expedientes*. In the construction as well as in its functions, it corresponds with the instrument in the Maragha observatory that was called *ālat ḏāt al-ğaib wa-s-samt* (above, no. VIII of the Maragha instruments). The only change Tycho Brahe made consists in the fact that the vertical arm slides only on one side on the horizontal grove, and not any more on the two sides as in the instrument of Maragha. The diameter of the circular wall amounted to 5 m in Tycho Brahe's model, the sum of the arms and the length of the horizontal groove was 3.5 m. The apparatus was constructed before 1602.

Tycho Brahé's Description of his Instruments, pp. 49–51; J.A. Repsold, *Zur Geschichte der astronomischen Meßwerkzeuge*, p. 26.

Our model:
Scale 1:4.
Diameter 50 cm.
Brass, engraved.
All rings have divisions in degrees engraved on both sides.
(Inventory No. A 4.10)

II.
Zodiacal Armillary Sphere

Tycho Brahe's armillary sphere which, as surmised by J. A. Repsold, must already have been constructed before 1570, is, in comparison with those of Ptolemy and of the observatories of Maragha and Istanbul, the most simple of its kind and at the same time the most advanced. The diameter of the meridian ring amounted to 1.95 m. The other three rings, colure ring, ecliptic ring and latitude ring, were of brass. The latitude ring and the ecliptic ring carried two sights each.

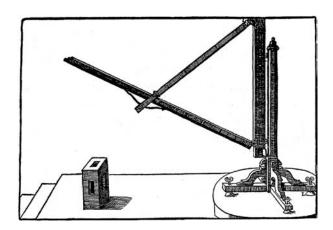
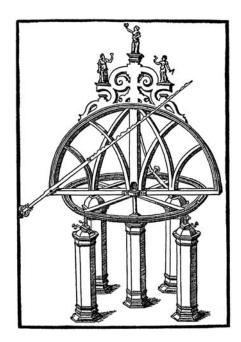
Tycho Brahé's Description of his Instruments, pp. 52–55; J.A. Repsold, *Zur Geschichte der astronomischen Meßwerkzeuge*, p. 26–27.

Our model:
Scale ca. 1:2.
Radius 80 cm.
Height from base to centre point 150 cm.
Hard wood, stained.
Brass scale with divisions in degrees.
(Inventory No. A 4.02)

III.

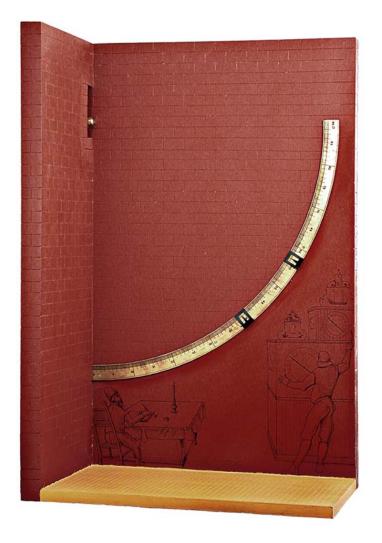
Astronomical Sextant for Distances

This sextant which Tycho Brahe calls *sextans astronomicus trigonicus pro distantiis rimandis* belongs to a type of which in the course of time he constructed three basically identical versions because, as he says, this instrument had proved itself to be especially suited for accurate observation. The sextant, freely movable, is attached to a relatively large ball that rests in a bowl. This makes it possible for the observer to move it vertically, horizontally, in the direction of east to west and in the opposite direction, and thus to determine not only altitudes on the meridian, but also distances of heavenly bodies from one another and thereby their position, as it was possible with the instrument of the Istanbul observatory which served the same purpose (above, no. VIII of the Istanbul instruments). It is particularly remarkable that with both the models, two wooden sticks were used for propping up the apparatus against the ground so that the readings could be recorded without impairment. The length of the arm of the sextant amounted to about 1.7 m. Judging from the proportions of the dimensions in the illustrations of the book, the instrument probably had a height of 2.5 m.

Tycho Brahé's Description of his Instruments, pp. 72–75; J.A. Repsold, *Zur Geschichte der astronomischen Meßwerkzeuge*, p. 28.

Our model:
Scale ca. 1:2.
Length of the arm
with sights 1 m.
Hard wood, stained.
Brass scale with divisions
in length.
(Inventory No. A 4.06)

IV.
Parallactic Ruler

The instrument called *instrumentum parallaticum sive regularum* by Tycho Brahe is an improved version of the Ptolemaic *órganon parallaktikón*. It was made of wood. The arm with the sights had a length of 1.7 m and carried two sights. Differing from the Ptolemaic model, the lower arm is long enough to allow measurements up to the horizon. When not in use, this arm is held up by a spring. The entire device is attached to a stand. The instrument was used for measuring distances near the zenith.

It was Mu'aiyadaddīn al-ʿUrḍī who realised that the Ptolemaic *órganon* was unserviceable; later Taqīyaddīn al-Miṣrī replaced it with a model which he himself developed (above, no. VI of the Istanbul instruments).

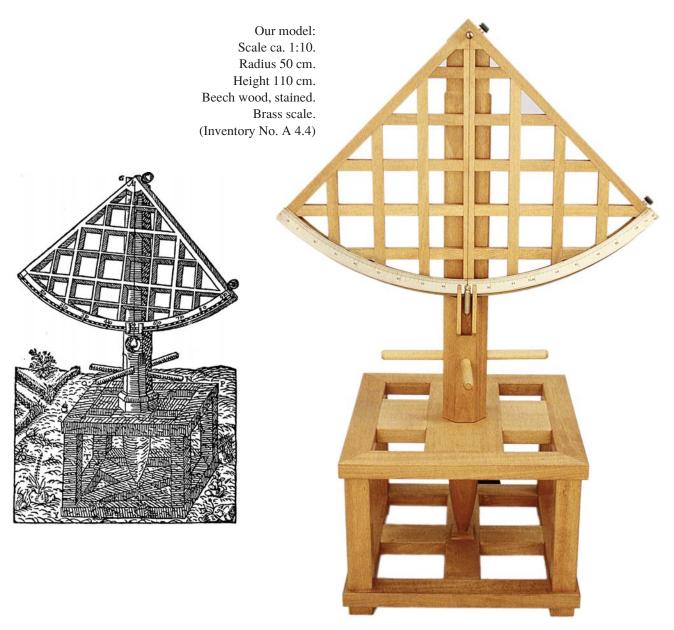
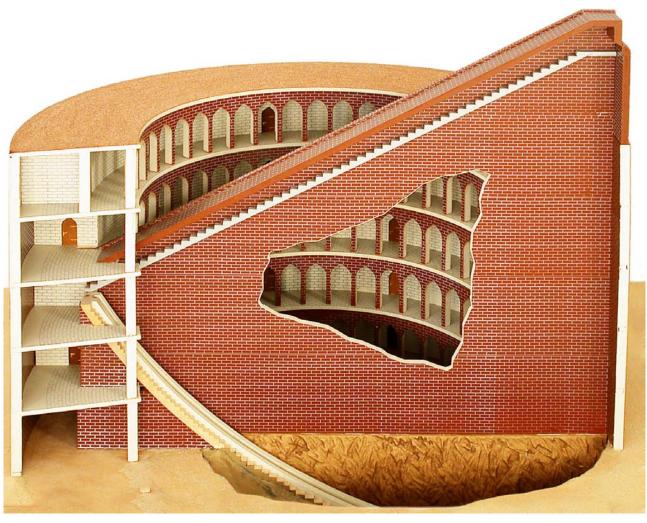
Tycho Brahé's Description of his Instruments, pp. 44–47; J.A. Repsold, *Zur Geschichte der astronomischen Meßwerkzeuge*, pp. 25–26.

Our model:
Scale ca. 1:10.
Diameter 50 cm.
Attachment of anodised brass,
with divisions in degrees on one side.
Rotating ruler pivoted to the
arc of the semicircle below.
(Inventory No. A 4.12)

V.
Large Azimuthal Semicircle

This instrument which Tycho Brahe calls *semicirculus magnus azimuthalis* in his book was probably constructed around 1587. "The alidade on the semicircle of altitudes is not pivoted at the centre, but at the end of the horizontal diameter in order to provide finer values of division; unfortunately it is not mentioned how the division, whose centre lies at the pivot of the alidade, that is to say eccentrically, was achieved and how it was read off. The iron azimuthal circle has a diameter of 2.5 m, an enclosed cross supports a vertical fixed central pivot around which the semicircle turns; in other respects it rests and glides on the horizontal circle." In the middle, hollow part of the semicircle a plummet is suspended (J. A. Repsold, *Astronomische Messwerkzeuge*, op. cit., p. 25). It is remarkable that this instrument of Tycho Brahe resembles the *ālat ḏāt as-samt* by Taqīyaddīn al-Miṣrī (above, no. III of the Istanbul instruments) and its predecessor from Damascus (above, p. 44), which were also constructed for determining altitudes and azimuths. However, with the predecessors the pivot of the alidade lay at the centre of the cross, not eccentrically as in Tycho Brahe's instrument.

Fig. extr. de Joan Blæu, *Atlas major,* Amsterdam, etc., 1662, vol. I.

Our model:
Scale ca. 1:10.
Wood, laminated.
50 × 30 × 80 cm.
Brass quadrant, scale of degrees;
2 sights and an adjustable visor.
(Inventory No. A 4.14)

VI. Mural Quadrant

The *quadrans muralis* is considered to be the chief instrument of Tycho Brahe. He is said to have constructed it in 1587. The brass apparatus, attached to a wall in the plane of the meridian, serves to determine the culmination altitudes. With its 4 m long radius, and its finely divided scale, exact results in measurement are possible to a large extent. The quadrant is equipped with two movable sights. Observations are made from one of the two sights through a gilded cylinder which is attached to an opening in the wall.
The pictorial representation of the scene of Tycho Brahe at work with his quadrant and other instruments, not all of which belong to the area of astronomy, recalls the depiction of the scene of work at the Istanbul observatory (above, p. 54).
We may mention here that the mural quadrant had been known in the Islamic world since al-Battānī (1st half 4th/10th c.) under the name *labina*. Constructed in large dimensions, it belonged to the collection of instruments of the observatories of Maragha (there no. I) and of Istanbul (there no. II).

Tycho Brahé's Description of his Instruments, op, cit., pp. 28–31; J.A. Repsold, *Zur Geschichte der astronomischen Messwerkzeuge*, op, cit., pp. 24–25.

Our model:
Scale ca. 1:10.
Radius 50 cm.
Height 110 cm.
Beech wood, stained.
Brass scale.
(Inventory No. A 4.4)

VII. Large Wooden Quadrant

According to his own statement, Tycho Brahe constructed the *quadrans maximus* in Augsburg 26 years before he wrote his book of instruments (1602), that is to say in 1576. Its radius measured 14 ells (ca. 6 metres). "The quadrant was attached to a vertical oak-beam, which tapered at the lower end and could be adjusted azimuthally in a heavy frame, but without a scale to measure the azimuth. It stood under the open sky and was of no use after a few years." For observations two aperture sights were used (*Tycho Brahe's Description of his Instruments*, op. cit., pp. 88-91; J. A. Repsold, *Zur Geschichte der astronomischen Messwerkzeuge*, op. cit., pp. 21-22).

This Tycho Brahe's instrument shows great similarity with the large wooden quadrant of Taqīyaddīn al-Miṣrī (no. V of the instruments of the Istanbul observatory), which Taqīyaddīn constructed at about the same time. It is possible that Tycho Brahe was informed about the Istanbul instrument. It is also likewise possible—and in my opinion more likely—that an earlier model of this instrument, such as that of the Maragha observatory (above, p. 44), was widely known in the Islamic world and served both as a model.

THE OBSERVATORY OF SAMARQAND

Our model:
Scale ca. 1:30.
Wood, laminated;
base area: 80 × 60 cm.
(Inventory No. A 5.04)

The observatory was founded by Muḥammad Ṭaraġāy b. Šāhruḫ Uluġ Beg (b. 796/1394, d. 853/1449), a grandson of Tīmūr. Uluġ Beg himself was an astronomer and was, no doubt, inspired for his enterprise by the Maragha observatory. The exact time of the construction and of the completion of the work is not known. "ʿAbd ar-Razzāq [as-Samarqandī in his *Maṭlaʿ-i saʿdain wa-maǧmaʿ-i baḥrain*] reports the construction of an observatory, while describing the events of the year 823/1420, namely in connection with the mosque-university or lodging for dervishes constructed in that year, although it is hardly possible to conclude that the observatory really originated at the same time as these buildings."[1] It became one of the most famous observatories of the Arabic-Islamic world, yet its ruins were thought to be lost until the first decade of the 20th century. "A part of the observatory was excavated under the supervision [**70**] of the government official Wjatkin, who was able to ascertain the location of the observatory only on the basis of hints in an old document, and the well-known astronomer Ossipoff, of the Tashkent observatory, could take the first, although still very rough, measurements on

[1] Wilhelm Barthold, *Uluġ Beg und seine Zeit*, German edition by Walter Hinz, Leipzig 1935 (reprint, in: Islamic Mathematics and Astronomy, vol. 54, Frankfurt 1998), p. 163.

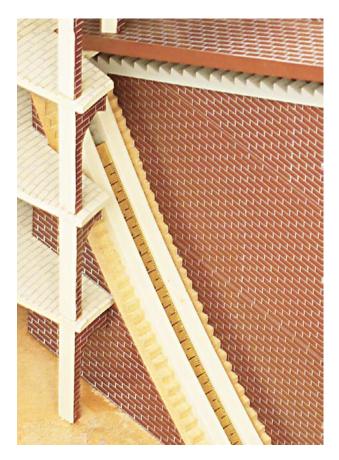
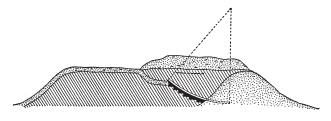
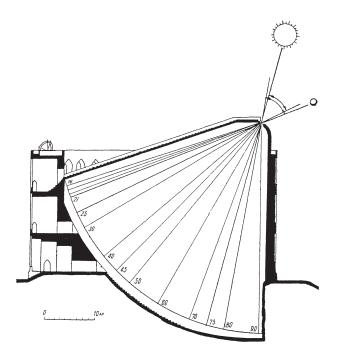
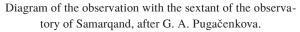
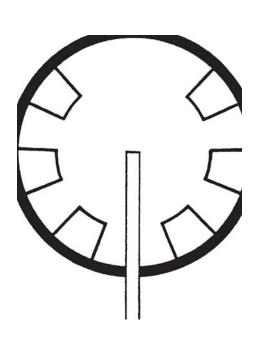



Photo (left): The sextant of the observatory of Samarqand, partially restored after excavations. (On the right, above: our model, detail).

[**70**] of the government official Wjatkin, who was able to ascertain the location of the observatory only on the basis of hints in an old document, and the well-known astronomer Ossipoff, of the Tashkent observatory, could take the first, although still very rough, measurements on the spot."[2]

The observatory was situated on a flat hill with a height of ca. 21 m, an east-western width of ca. 85m and a north-southern length of ca. 170 m.[3]

Section of the hill on which Uluġ Beg's observatory stood[4].

[2] K. Graff, *Die ersten Ausgrabungen der Ulugh-Bek-Sternwarte in Samarkand*, in: Sirius. Rundschau der gesamten Sternforschung für Freunde der Himmelskunde und Fachastronomen (Leipzig) 53/1920/169–173, esp. p. 170 (reprint in: Islamic Mathematics and Astronomy, vol. 55, Frankfurt 1998, pp. 363–367, esp. p. 364).

[3] A. Sayılı, *The Observatory in Islam*, op. cit., pp. 274–275.
[4] After K. Graff, op. cit., p. 170 (reprint, op. cit., p. 364).

Diagram of the observation with the sextant of the observatory of Samarqand, after G. A. Pugačenkova.

Ground plan of the foundation for the tower at the observatory of Samarqand

[**71**] The surviving ruins lead to the conclusion that it is a circular foundation with a diameter of ca. 46 m. It is assumed that the height of the building, formed like a cylinder, was approximately 30 m above ground. This calculation is based on the radius of the scale in the plane of the meridian, situated between two arcs equipped with steps, which is not seriously damaged. With a diameter of ca. 60 m, this sextant represents a further development of the Faḫrī sextant. The approximate ground plan of the establishment conveys the impression of a generously laid out observatory. The instruments used in the observatory of Samarqand may have consisted mainly of those which Ġiyāṯaddīn al-Kāšī, one of the most important scholars of this observatory, described in his treatise *Risāla dar šarḥ-i ālāt-i raṣad*:[5]

"1. the instrument with the two arms,
2. the instrument with the rings,
3. the equatorial ring,
4. the two rings,
5. the al-Faḫrī sextant,
6. the instrument for determining azimuth and altitude,
7. the instrument with the sine and the versed sine,
8. the instrument with the small ring or the small rings."[6]

[5] MS Leiden, University Library, Or. 945 (fol. 12–13, 818 H., v. M.J. de Goeje, *Catalogus codicum orientalium Bibliothecae Academiae Lugduno–Batavae*, vol. 5, Leiden 1873, p. 245); ed. by W. Barthold in: *Uluġbek i ego vremja*, in: Mémoires de l'Académie des Sciences de Russie, 8e série, vol. 13, nº 5, Petersburg 1918 (app. I omitted in the translation by W. Hinz, *Uluġ Beg und seine Zeit*); E.S. Kennedy, *Al-Kāshī's Treatise on Astronomical Observational Instruments*, in: Journal of Near Eastern Studies (Chicago) 20/1961/98; v. also A. Sayılı, *The Observatory in Islam*, op. cit., p. 283. See also Julius Smolik, *Die Timuridischen Baudenkmäler in Samarkand aus der Zeit Tamerlans*, Vienna 1929, fig. nº 89; G.A. Pugačenkova, *Architektura komposicia observatorii Ulugbeka*, in: Obščestvennye nauki v Uzbekistane (Tashkent) 13/1969/30–42; Lisa Golombek and Donald Wilber, *The Timurid Architecture of Iran and Turan*, Princeton1988, vol. 1, pp. 265–267, vol. 2, nº 96.

[6] H.J. Seemann, *Die Instrumente der Sternwarte zu Marâgha*, op. cit., p. 17 (reprint, op. cit., p. 83).

Our model:
Scale 1:100.
Size of the base plate 130 × 110 cm.
Wood and synthetic material.
(Inventory No. A 5.02)

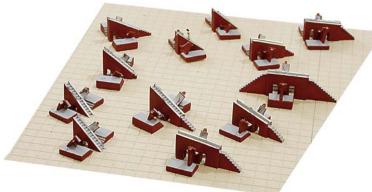
General Informations and the Observatory of Jaipur

Astronomy and mathematical geography, cultivated very meticulously in Tīmūr's Samarqand by Sultan Uluġ Beg and his astronomers, shifted to India along with political power as a consequence of the establishment of the Moghul empire by Bābur in 932/1526. The astronomical observational instruments and the tables of localities which were prepared there until the beginning of the 18th century should be considered the continuation of the Samarqand school of astronomers.[1]

This work, continued in India from the middle of the 16th century onwards, came to a close with the intense and spectacular activities of the Hindu scholar and statesman Jai Singh Sawāʾī (1686-1743). Inspired by the fame of the grandly laid out Samarqand observatory, he had enormous observatories built in Delhi, Jaipur, Benares, Ujain (Ujjain) and Madura, equipped with instruments of huge dimensions. They were founded between 1722 and 1739. The first came up in Delhi and was called Jantar Mantar (distorted from Yantra Mantra).

[1] Voir F. Sezgin, *Geschichte des arabischen Schrifttums,* vol. 10, pp. 193 ff.

Plan of the observatory of Jaipur, drawn by G.R. Kaye.

The excellents studies by G.R. Kaye[2] and W.A. Blanpied[3] and photographs, recently taken for us, enabled us to prepare the models of the two observatories in the workshop of our Institute.

[2] *The Astronomical Observatories of Jai Singh*, Calcutta 1918; idem, *A Guide to the Old Observatories at Delhi; Jaipur; Ujjain; Benares*, Calcutta 1920.
[3] *The Astronomical Program of Raja Sawai Jai Singh II and its Historical Context*, in: Japanese Studies in the History of Science (Tokio) 13/1974/87–126.

The most important instruments:

Samrāṭ Yantra, the largest of all the instruments in the Indian observatories, is nearly 27.50 m (90 feet) high and 44.80 m (147 feet) long. It is an equinoctial sundial and consists of a gnomon in the form of a right-angled triangle set in the plane of the meridian, connected with two quadrants, the radius of which comes to 17.50 m (49 feet and 10 inches) each. The general structure corresponds with the instrument at the observatory of Delhi, but with improved construction and a larger scale. A sextant was built in the two walls, both times underground. However, it is doubtful whether these sextants could function at all. The observatory of Delhi has only one sextant in this place.

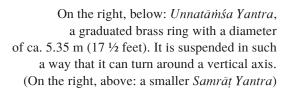
Rāśīvalaya Yantra, the "ecliptic-instrument", consists of twelve sun-dials, one for each sign of the zodiac

Jai Prakāś consists of two concave hemispheres with cut out walkways, in the inner surfaces of which circles of altitude and azimuth, right ascensions and declinations are marked. Above the hemispheres, cross-wires are drawn whose shadow serves to determine the Sun's altitude. The Delhi observatory possesses for this purpose only one hemisphere.

Kapāla consists of two complete hemispheres with a diameter of 3.45 m (11 ⅓ feet). The rim of one represents the horizontal circle, that of the other the solstitial colure. The inner surface of the first one carries lines of the meridian, that of the other right ascensions. This instrument is absent in the Delhi observatory.

Rām Yantra corresponds with a cylindrical astrolabe with orthogonal projection. In the middle of the instrument, which is open at the top, stands a pillar. The inner surfaces carry tangent scales for determining altitudes and azimuths. Two large instruments of this kind stand in the observatory of Delhi, four smaller ones in Jaipur. G. R. Kaye was of the opinion that three of these four instruments were built subsequently. He included therefore only one in his plan of the overview.

Digamśa Yantra is an instrument for the determination of azimuths. Similar instruments are also in the observatories of Ujjain and Benares. In Delhi it is absent.

Dakshiṇovṛitti Yantra, a double quadrant on a wall, as we know it from the Istanbul observatory (there no. II). The radius of the Jaipur quadrants amounts to about 6 m (20 feet) each.

(back side)

On the left: *Narivalaya Yantra*, a cylindrical wall with a diameter of ca. 3 m (10 feet), functions as a sundial

On the right, below: *Unnatāṁśa Yantra*, a graduated brass ring with a diameter of ca. 5.35 m (17 ½ feet). It is suspended in such a way that it can turn around a vertical axis. (On the right, above: a smaller *Samrāṭ Yantra*)

The observatory
Jantar Mantar
in Delhi.

Our model:
Scale 1:100.
Size of the base plate 130 × 80 cm.
Wood and synthetic material.
(Inventory No. A 5.01)

It is the first observatory and was built in 1134/1722 during the Moghul rule in India, and contains the following instruments:

1. *Samrāṭ Yantra*, corresponds with the instrument with the same name at Jaipur. Ground area ca. 38 m (125 feet) from east to west, ca. 36.50 m (120 feet) from north to south. Height ca. 20.75 m (68 feet), radius of the quadrants ca. 15 m (49 ½ feet).

2. *Jai Prakāś*, like the instrument with the same name at Jaipur.

3. *Rām Yantra*, cf. the instrument with the same name at Jaipur. The height of the walls and of the pillar correspond with the inner radius of the structure, measured from pillar to wall; it amounts to ca. 7.50 m (24 feet and 6 ½ inches). The diameter of the pillar measures ca. 1.60 m (5 feet and 3 ½ inches).

4. *Miśra Yantra*, situated to the north-west of the *Samrāṭ Yantra*, is called the "mixed instrument", since it combines in one structure four different instruments. Among them are a gnomon with two graduated semicircles on each side, one more graduated semicircle for finding the meridian altitudes (*Dakshiṇovṛitti Yantra*, above, under Jaipur) and a broad graduated circle which represents the latitude of the northern tropic and shows an inclination of 5° to the horizontal plane of Delhi (28° 37').

On errors with Measuring instruments

"Since in the manufacture of measuring instruments it is not possible to achieve the desired precision, be it with the evenness of the surfaces or with the marking of the divisions or holes at the right place, it is but natural that errors occur, as with the adjustment of the instruments. In almost every construction inaccuracies exist, whether visible or hidden. If the instrument is made of wood, then it will warp, particularly when it stands at a place exposed to Sun and humidity. The errors are larger or smaller, according to the theoretical knowledge, craftsmanship and experience. Added to this, there is the expertise of the observer in setting up and measuring, the precision of the adjusting apparatus and much more. Whosoever believes that anybody can execute measurements on order and without previous practice, and that each measuring instrument delivers correct results, is in error. Whosoever wishes to achieve this must, first of all, spend a long time on the study of the instruments and on the practice in measuring, until finally his measurement rests on the knowledge of the precision of his instrument and on his experience in measuring."

Ibn Yūnus[1] (d. 399/1009);
translation after Eilhard Wiedemann[2].

[1] *Kitāb az-Zīǧ al-kabīr al-Ḥākimī*, extracts ed. and translated into French by A.-P. Caussin de Perceval in: Notices et Extraits des manuscrits de la Bibliothèque nationale et autres bibliothèques (Paris) 7, 12/1803-04/16-20, here pp. 80/81-82/83 (reprint in: Islamic Mathematics and Astronomy, vol. 24, Frankfurt 1997, pp. 54-278, ici pp. 118/119-120/121).
[2] *Zur islamischen Astronomie*, op. cit. p. 122 (reprint in: *Gesammelte Schriften*, vol. 2, p. 906

The astrolabe

The astrolabe, the most wide-spread and most popular instrument in the history of astronomy, reached the Arabic-Islamic world from Persian, Syrian and other centres of science in the eastern Mediterranean area, where Greek sciences were cultivated prior to Islam and in early Islamic times. In its simplest form it was already known to the Greeks presumably already in the 2nd, perhaps even already in the 4th c. B.C. The names Hipparchus (2nd c. B.C.), Apollonius (2nd c. B.C.), or Eudoxus (4th c. B.C.) are linked with its invention. In any case, it is mentioned by Ptolemy in his tract on the projection of the spherical surface on the plane surface.[1] The astrolabe also seems to have passed through a certain process of development in Late Antiquity. The science historian Ibn an-Nadīm (4th/10th c.) knew a work by Theon of Alexandria (4th c. A.D.) on the use of the astrolabe (*Kitāb al-ʿAmal bi-l-asṭurlāb*).[2] This seems to be identical with a book which was translated in the 2nd/8th c. under the title *Kitāb fī Ḏāt aṣ-ṣafāʾiḥ wa-hiya l-asṭurlāb* as a work by Ptolemy and which was described as such in detail by the historian al-Yaʿqūbī (3rd/9th c.).[3]

The astrolabe itself must have been known in the Arabic-Islamic area, if not already in the 1st/7th century, then in the first half of the 2nd/8th century. The Arabic titles of books known to us, the extant fragments and books convey the impression that the books on astrolabes which originated in the Islamic world in the 2nd/8th and 3rd/9th century contributed to the development of a constantly improving literature on applied astronomy. The theoretical element preserved in this literature shows that we can place the beginning of the creative period of the Arabic-Islamic culture in the history of the astrolabe in the first half of the 3rd/9th century.

“The astrolabe is a portable instrument which adjusts itself into an exactly vertical position through a type of Cardanic suspension. One of its main parts is a stationary disc on which the horizon is projected with its parallel circles and vertical circles (*muqanṭara* and azimuthal circles) from a point, mostly from one of the celestial poles. The horizontal line divides the disc into two parts, into an upper part with the projections of the *muqanṭara* and azimuthal circles, which corresponds to the half of the celestial sphere above the earth, and into a lower part that corresponds to the half of the celestial sphere beneath the earth. On this lower part several arcs are drawn from the centre of the disc up to the rim; these are designated as hour lines. It has to be kept in mind that the counting of the hours begins with sunrise, according to ancient customs. The other main part of the instrument is a movable disc which, however, is not solid but an open-work piece. On it are seen the projection of the ecliptic (of the zodiac) which, corresponding with the number of the signs of the zodiac, is divided into 12 parts; these are further subdivided into 30 degrees. There are also the projections of a number of the largest and most well-known fixed stars.”

“The movable disc, called spider or net [*ʿankabūt* or *šabaka*], can be rotated around an axis at its centre upon the stationary disc. By rotating the spider, the daily rotation of the heavenly bodies at a given local horizon can be simulated. If the spider is set up in a particular position, it is possible to read off the altitude above the horizon and the azimuth directly on the disc which is under the spider, for each of the stars and signs of the zodiac represented on the spider, for the Sun and, in a certain sense, the planets included, and can read off the hours, which have elapsed since sunrise or sunset, from the intersection with the hour lines of the point of the zodiac sign where the Sun is situated just then, or of the point in the zodiac diametrically opposite to the Sun …”

“The astrolabe makes it possible to directly determine the stars in the following main positions. It is only necessary to see which heavenly body lies, with a [**80**] particular position of the spider, on the eastern or western part of the horizon, on the

[1] v. Josef Frank, *Zur Geschichte des Astrolabs*, Erlangen 1920 (reprint in: Islamic Mathematics and Astronomy, vol. 35, Frankfurt 1998, pp. 1–33), p. 6.

[2] v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 6, p. 102.

[3] v. ibid., vol. 5, p. 173, 180.

upper or lower part of the meridian line, which is the vertical diameter of the disc. In order to be able to situate the spider at a position corresponding with the given position of the celestial sphere, it is necessary to know one of the above-mentioned astronomical data, be it e.g. the altitude of a star or of the Sun above the horizon, be it the hour that has elapsed since sunrise. By rotating the spider, the star is placed on the muqanṭara in accordance with its altitude, or at night by giving the hour, and that is to say the hour of the night, the position of the Sun in the zodiac, and with the time of the day, the point situated diametrically opposite the Sun's position upon the respective hour line. The spider then shows the desired position. Besides these few problems mentioned, quite a number of other astronomical and astrological problems can be solved mechanically with the astrolabe, almost without calculation"[4].

The enormous development in professional, technical, artistic and literary respects which this chief instrument of Arabic-Islamic astronomy underwent through the centuries has been dealt with more comprehensively by modern research than most other topics of Islamic history of science.

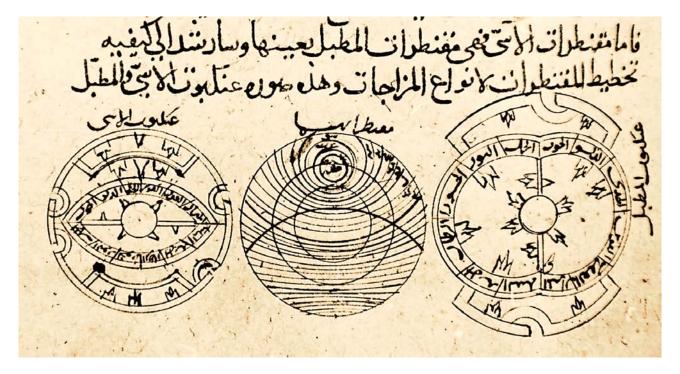
The common astrolabe or planispheric astrolabe, Arabic *asṭurlāb musaṭṭaḥ* or *asṭurlāb saṭḥī*, has one to nine discs (*ṣafīḥa*, pl. *ṣafāʾiḥ*), which are valid for the degrees of latitude of those places whose horizontal coordinates are engraved. The other parts are called *ʿurwa* or *ḥabs* = handle; *ḥalqa* or *ʿilāqa* = ring; *ḥuǧra*, *kuffa* or *ṭauq* = the raised, circular rim or limb; *umm* = "mater", the main part of the instrument in which the discs and the spider are stacked; *ʿankabūt* or *šabaka* = spider or net; *waǧh* = the inner side of the mater; *ẓahr* = "back" of the mater; *ʿiḍāda* = alidade, diopter; *šaṭbatān* or *šaẓīyatān* = the two tips of the alidade; *libna*, *daffa* or *hadaf* = sight vanes; *ṯuqbatān* = the two apertures of the sight vanes; *miḥwar*, *quṭb* = axis, pin which is inserted through a hole at the centre of the mater, of the discs and of the spider and which holds these together; *faras* = "horse", a wedge that is pushed through a hole at the tip of the axis and holds tight the discs and the spider in the "mater".[5]

The signs of the advanced development which the astrolabe underwent in the Arabic-Islamic period include its numerous variants. The types known until the turn of the 4th/10th to the 5th/11th century are described by Abu r-Raiḥān al-Bīrūnī in his book *Istīʿāb al-wuǧūh al-mumkina*[6] in which he leans heavily on a book by his teacher Abū Saʿīd Aḥmad b. Muḥammad as-Siǧzī[7] (2nd half 4th/10th c.). From the studies on the various types of astrolabes done so far, it is evident that there is a connection between their origin and the concept of the mixed astrolabes (*mizāǧ al-asṭurlāb*). This has to do with the combination of the features of the northern and the southern astrolabe in a single one. As early as in the first half of the 3rd/9th century, the Arabs were—in the words of J. Frank[8]—"not content with the form adopted from their predecessors where the part of the celestial sphere to the north of the tropic of Capricorn is projected upon a plane parallel to the celestial equator or upon itself from the south pole. They also attempted stereographic projection from the north pole of that part of the celestial sphere which lay south of the tropic of Cancer and called an astrolabe thus produced the southern astrolabe, as distinct from the northern astrolabe. When exactly the southern one originated cannot be ascertained any more, but in any case before Farġânî, who also provides the theory for this astrolabe."

Al-Bīrūnī[9] describes the variants of the northern and southern astrolabe in his book in the chapter *kaifīyat ǧamʿ nauʿai l-asṭurlāb aš-šimālī wa-l-ǧanūbī wa-mizāǧ aškālihā baʿḍihā bi-baʿḍ*.

[4] Josef Frank, *Zur Geschichte des Astrolabs*, pp. 4–5 (reprint, op. cit., pp. 4–5).

[5] Franz Woepcke, *Über ein in der Königlichen Bibliothek zu Berlin befindliches arabisches Astrolabium*, Berlin 1858, p. 1–3 (reprint in: Islamic Mathematics and Astronomy, vol. 86, pp. 3–5).

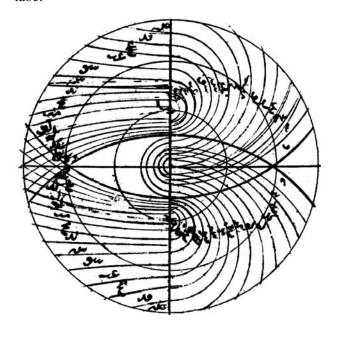
[6] v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 6, p. 268.

[7] Ibid. pp. 225–226.

[8] *Zur Geschichte des Astrolabs*, op. cit., p. 8 (reprint p. 8).

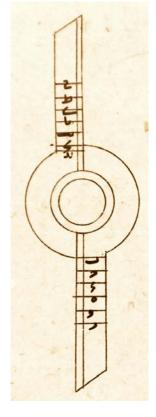
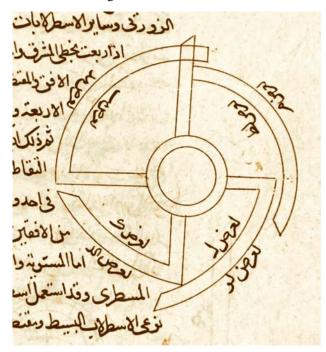
[9] *Istīʿāb al-wuǧūh al-mumkina*, MS Istanbul, Ahmet III, 3505 (no page numbers).

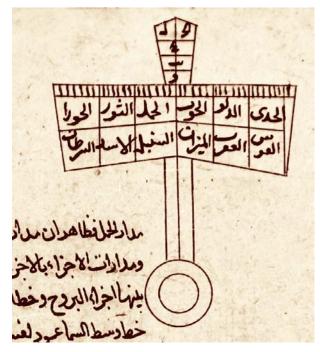
They are "named after the objects which the shape of the spider, particularly that of the zodiac, calls to mind. The outer form of the astrolabe does not differ in this regard from that of the common astrolabe."[10]

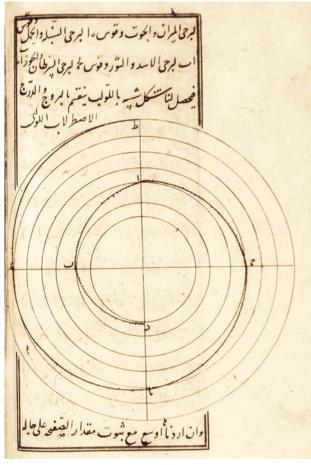
The variants described by al-Bīrūnī are: *al-asṭurlāb al-muṭabbal* (the astrolabe shaped like a drum, on the right in the following picture), *al-asṭurlāb al-āsī* (the astrolabe shaped like a myrtle, on the left in the picture); here the drawings of their spiders or retes:

Al-Bīrūnī, *Istīʿāb*, MS Ahmet III, 3505.

Al-asṭurlāb al-musarṭan (the astrolabe shaped like a crab) has the following rete:

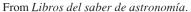
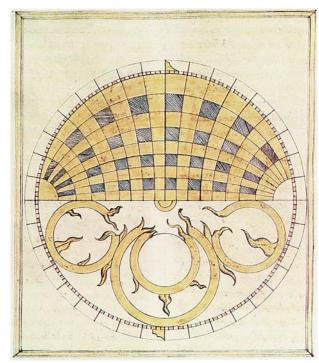
Al-Bīrūnī, *Istīʿāb*, MS Carullah 1451, fol. 23 a.

[10] J. Frank, *Zur Geschichte des Astrolabs*, op. cit., p. 9 (reprint, op. cit., p.9).

The parallels of altitude of the crab-shaped astrolabe:

Al-Bīrūnī, *Istīʿāb*, MS Ahmet III, 3505.

Al-asṭurlāb al-misṭarī (the ruler-shaped astrolabe) has the following rete:

Al-Bīrūnī, *Istīʿāb*, MS Carullah 1451.

Al-asṭurlāb az-zauraqī (the ship-shaped astrolabe) has the following rete:

Al-Bīrūnī, *Istīʿāb*, MS Carullah 1451, fol, 29b.

Al-asṭurlāb aṣ-ṣalībī (the cross-shaped astrolabe) has the following rete:

Al-Bīrūnī, *Istīʿāb*, MS Carullah 1451, fol, 30b.

Al-asṭurlāb al-laulabī (the spiral-shaped astrolabe) has the following rete:

Al-Bīrūnī, *Istīʿāb*, MS Oxford, Bodl., Marsh 701, fol. 274b.

Less than a quarter of a century after al-Bīrūnī's death (d. 440/1048), there appeared universal astrolabes which were no longer provided with discs designed for specific latitudes. The first known step in this direction was taken by Abu l-Ḥasan ʿAlī b. Ḫalaf. The astrolabe that carries his name was called in later centuries *šakkāzīya*. We know the rete of the instrument[11] through an illustration in the *Libros del saber de astronomía*:

From *Libros del saber de astronomía*.

The upper half of the rete forms a net of almucanters and azimuth circles, the lower half carries star positions. We learn the details about ʿAlī b. Ḫalaf's instrument from the Castilian translation of his treatise in the *Libros del saber de astronomía*.[12]

The history of astronomy knows another astrolabe with similar projection, designed at about the same time in Andalusia and known under the name of the great astronomer Ibrāhīm b. Yaḥyā az-Zarqālī (or Zarqāllū, 2nd half 5th/11th c.). His astrolabe, known in the Arabic-Islamic world as *ṣafīḥa zarqālīya* and in modern research as the universal disc, is also described in detail in the *Libros del saber de astronomía*. There az-Zarqālī's tract is reproduced in the Castilian translation of the [**84**] original version[13] dedicated to the ruler al-Muʿtamid b. ʿAbbād (ruled 461/1068-484/1091) (below, p. 118).

[11] *Astronomical Instruments in Medieval Spain*, Santa Cruz de la Palma 1985, p. 90; *El legado científico Andalusí*. Museo Arqueológico Nacional, Madrid 1992, p. 235; Emilia Calvo, *La lámina universal de ʿAlī b. Jalaf (s. XI) en la versión Alfonsí y su evolución en instrumentos posteriores*, in: *‹Ochava espera› y ‹astrofísica›. Textos y estudios sobre las fuentes árabes de la astronomía de Alfonso X.*, ed. Mercè Comes, Honorino Mielgo y Julio Samsó, Barcelona 1990, pp. 221–231.

[12] Ed. Manuel Rico y Sinobas, vol. 3, Madrid 1864, pp. 1–132; Emmanuel Poulle, *Un instrument astronomique dans l'occident latin, la ‹saphea›*, in: Studi Medievali (Spoleto), serie terza 10/1969/491–510.

[13] Ed. Manuel Rico y Sinobas, vol. 3, Madrid 1864, pp. 135–237; v. José M. Millás Vallicrosa, *Un ejemplar de azafea árabe de Azarquiel*, in: Al-Andalus (Madrid and Granada) 9/1944/111–119 (reprint in: Islamic Mathematics and Astronomy, vol. 40, Frankfurt 1998, pp. 233–243.

Az-Zarqālī's astrolabe "consists only of one single disc on which the celestial equator and the ecliptic with their parallel circles and vertical circles are projected from the first point of Aries or that of Libra upon the plane of the solstitial colure. Since the first point of Aries or that of Libra constitute at the same time the east and the west points of every horizon, the disc is valid for all latitudes. The horizon itself is projected through a straight line passing through the centre of the projection; the straight line is represented by a ruler, movable around the centre and provided with divisions. With the help of the division of degrees on the rim of the disc the ruler can be assigned any location according to the position occupied by the horizon on the celestial sphere in relation to the equator. The back is usually that of the common astrolabe, except that there is also a smaller circle on it through which the orbit of the moon can be represented."[14]

ʿAlī b. Ḫalaf's book and astrolabe did not have as much impact as az-Zarqālī's book and instrument on the further development of the astrolabe. The extent of this impact on astronomical literature and on the art of astrolabe making was described brilliantly by Emmanuel Poulle[15] in his study on *Un instrument astronomique dans l'occident latin, la "saphea"*. The impact lasted from the beginning of the 13th century into the 16th century, which means that Europe had already known about az-Zarqālī's universal disc and his tract for more than half a century before it was included in the *Libros del saber de astronomía* of Alfons X. The the most recent and artistically most delicate specimens of this type of astrolabe, which were made in Europe, include those of Walter Arsenius (ca. 1570), Erasmus Habermel (ca. 1585) and John Blagrave[16] (ca. 1585), the first two of whom are represented with models in our Museum (below, p. 113 ff.). In this connection we may recall the important statement by Emmanuel Poulle[17], namely that in Europe the practical interest in these astrolabes by no means aimed at contributing to astronomical observations or precise calculations.

In the Arabic-Islamic world the universal disc also had a rather wide impact. Its extent, in literary as in practical fields, was discussed by Emilia Calvo Labarta in her study on and edition of *Risālat aṣ-Ṣafīḥa al-ǧāmiʿa* by al-Ḥusain b. Bāṣuh (d. 716/1316), which contains a detailed description of the instrument.[18]

The development outlined here led to the emergence of the astrolabe of Aḥmad b. Abī Bakr Ibn as-Sarrāǧ (d. ca. 730/1330), who was active in Syria. His instrument combines in itself the advantages of the conventional planespherium with those of the universal disc and, beyond that, embodies the highest mathematical-astronomical standard that the astrolabe ever achieved in the East and in the West (below, p. 119).

Finally mention may be made of two other types of astrolabe developed in the Arabic-Islamic area. One of them is the spherical astrolabe, the other the linear astrolabe. We can trace the origin of the spherical astrolabe back to the second half of the 3rd/9th century. It is assumed that it was invented by Ǧābir b. Sinān al-Ḥarrānī.[19] He was followed [**85**] after a short time by several astronomers like Ḥabaš al-Ḥāsib (still alive around 300/912)[20], Qusṭā b. Lūqā (d. around the turn of the 3rd/9th to the 4th/10th c.)[21] and al-Faḍl b. Ḥātim an-Nairīzī (early 4th/10th c.)[22] as well as subsequent scholars like Abu r-Raiḥān al-Bīrūnī (d. 440/1048)[23] and Abu l-Ḥasan al-Marrākušī (2nd half of the 7th/13th c.). This type of astrolabe also went through a long development in the Arabic-Islamic world. It appears, however, that it either did not come to the knowledge of scholars in Europe outside Spain or was not taken account of. The construction of the

[14] J. Frank, *Zur Geschichte des Astrolabs*, op. cit., p. 32 (reprint, p. 32); v. also C. A. Nallino, *Asṭurlāb*, in: Enzyklopaedie des Islām, vol. 1, Leiden 1913, pp. 521-522 (reprint in: Islamic Mathematics and Astronomy, vol. 87, Frankfurt 1998, pp. 363-365, esp. pp. 364-365); D. King, *On the Early History of the Universal Astrolabe in Islamic Astronomy, and the Origin of the Term Shakkāzīya in Medieval Scientific Arabic*, in: Journal for the History of Arabic Science (Aleppo) 3/1979/244-257.

[15] Dans: Studi Medievali (1969).

[16] v. R.T. Gunther, *The Astrolabes of the World*, Oxford 1932, pp. 492 ff.

[17] *Un instrument astronomique*, p. 510.

[18] Abū ʿAlī al-Ḥusayn ibn Bāṣo (d. 716/1316), *Risālat al-ṣafīḥa al-ŷāmiʿa li-ŷamīʿ al-ʿurūḍ (Tratado sobre la lámina general para todas las latitudes)*, ed., trad. y estudio Emilia Calvo Labarta, Madrid 1993, pp. 27–32.

[19] v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 6, p. 162.

[20] Ibid., pp. 173–175.

[21] Ibid., pp. 180–182.

[22] Ibid., pp. 191–192.

[23] Ibid., pp. 261–276.

spherical astrolabe and its use will be dealt with in connection with the reconstructed models (below, pp. 120-133).

As far as the linear astrolabe is concerned, which we will also discuss in connection with a model (below, p. 134), it represents in principle nothing but the attempt to take observations that are normally made with the planespheric astrolabe by means of a graduated rule. The scholar who made this attempt was Šarafaddīn al-Muẓaffar b. Muḥammad aṭ-Ṭūsī (d. ca. 610/1213), to whom an important position is also due in the history of mathematics.[24]

While summing up, we may cite the comparative verdict on the astrolabes from the Arabic-Islamic world and those from Europe of a young and unbiased scholar in his study on Die Astrolabiensammlungen des *Deutschen Museums und des Bayerischen Nationalmuseums*:[25] "Study of the Islamic pieces provides evidence of the progress of Islamic instrument making which impressed me and shows the power of technical innovations of the Islamic instrument makers. The Islamic instruments always prove themselves to be pieces that combine the highest astronomical utility and, at the same time, elegant artistic grace. The study of Islamic astrolabes brings to light only few specimens which are not in keeping with this general statement."

"The European astrolabes, on the other hand, lack a constantly high quality spanning centuries. Some European instruments testify to a high standard of astrolabe construction. Other pieces which, as far as the workmanship is concerned, are often not inferior to the astronomically valuable specimens, testify on the other hand to the elementary astronomical incomprehension of their creators. This reflects the differences in the tradition of astronomical knowledge in Europe and the incompleteness of the transmission of this knowledge from the medieval Islamic area."

[24] Ibid., p. 399.

[25] Written by Burkhard Stautz, Munich: Deutsches Museum, 1999, p. 5.

Our model:
Brass, etched.
Mater with bracket and suspension ring with a diameter of 170 mm.
One disc.
(Inventory No. A 2.25)

The Astrolabe
of Nasṭūlus

Nasṭūlus, with the names Muḥammad b. Muḥammad (or ʿAbdallāh), seems to have lived in the last quarter of the 3rd/9th and in the first quarter of the 4th/10th century.[1] He was among the most well-known astrolabe makers of his times and is also said to have been the inventor of the so-called eclipse disc (*aṣ-ṣafīḥa al-kusūfīya*). His famous astrolabe was in the possession of Alain Brieux in Paris in the last century.[2] Meanwhile another astrolabe from the first half of the 4th/10th century became known, the mater of which seems to be by Nasṭūlus. In the catalogue of the Museum of Islamic Art in Cairo Nasṭūlus al-Wāsiṭī is mentioned as its maker.

The astrolabe described here is today in the possession of the Islamic Archaeological Museum in Kuwait.[3] It was made in 315/927, has a diameter of 173 mm and a thickness of 4 mm. It has a single disc, one side of which at 33° is meant for Baghdad and the other for a place with the latitude of 36°. The rete shows 17 fixed stars.

[1] v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 6, pp. 178-179, 288.

[2] Fr. Maddison, A. Brieux, *Basṭūlus or Nasṭūlus? A Note on the Name of an Early Islamic Astrolabist*, in: Archives internationales d'histoire des sciences (Paris) 24/1974/157–160; D.A. King, *A Note on the Astrolabist Nasṭūlus/Basṭūlus*, in: Archives internationales d'histoire des sciences (Paris) 28/1978/117–120

[3] D.A. King, *Early Islamic Astronomical Instruments in Kuwaiti Collections*, in: *Kuwait. Art and Architecture. A Collection of Essays*, Kuwait 1995, pp. 77–96, esp. pp. 79–83.

Our model:
Brass, etched.
Mater with a diameter of 130 mm.
Without rete, alidade or disc.
(Inventory No. A 2.26)

The Second
Astrolabe
of Nasṭūlus

A part of another astrolabe by the same Nasṭūlus (Muḥammad b. Muḥammad or ʿAbdallāh) is preserved in the Museum of Islamic Art in Cairo. It consists of the "mater" (*umm*) together with the rim (*ḥuǧra*) and the "throne" (*kursī*). The name Nasṭūlus is engraved on the back of the kursī. What is surprising in this astrolabe is that the names of 64 cities with their latitudes are inscribed on the inner surface of the umm. Its diameter is 13 cm.

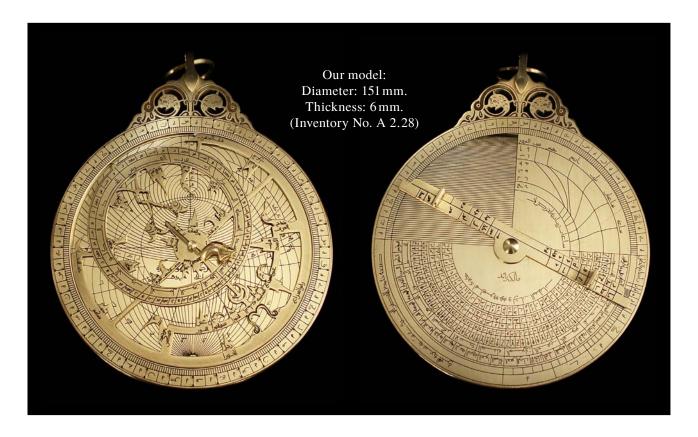
David A. King, Paul Kunitzsch, *Nasṭūlus the Astrolabist once again*, in: Archives internationales d'histoire des sciences (Paris) 33/1983/342–343; D. A. King, *Bringing Astronomical Instruments back to Earth—The Geographical Data. On Medieval Astrolabs (to ca. 1100)*, in: *Between Demonstration and Imagination*. Essays in the History of Science and Philosophy Presented to John D. North, Leiden 1999, ppp. 1–53, esp. pp. 10, 29–30.

The Astrolabe
of Ḥāmid b. ʿAlī al-Wāsiṭī

Our model:
Brass, etched.
Mater with bracket and
suspension ring with a diameter of 111 mm.
One disc.
(Inventory No. A 2.27)

The astronomer Abu r-Rabīʿ Ḥāmid b. ʿAlī from al-Wāsiṭ seems to have lived in the first half of the 4th/10th century. The famous astronomer ʿAlī b. ʿAbdarraḥmān Ibn Yūnis[1] (d. 390/1009) referred to him and to ʿAlī b. ʿĪsā al-Asṭurlābī as the two most important astrolabe makers. In his extant treatise on the use of the spherical astrolabe, Ḥāmid al-Wāsiṭī stresses the advantages of this type of astrolabe over the planispheric type.[2]
A mater from his astrolabes is preserved in the Museum of Islamic Art in Cairo (Inv. No. 15354).

Unfortunately, a rete has been affixed inseparably to the mater with the result that it is not possible to examine the inner side of the latter. The rete seems to date from the 8th/14th century. The mater carries, on three quadrants at the back, the names of the signs of the zodiac in Arabic script and furthermore their symbols, which are called *ḥudūd al-Miṣrīyīn*. The last quadrant is designed as a sine quadrant. The diameter of the mater is 11 cm.

[1] v. A.P. Caussin de Perceval, *Le livre de la grande table Hakémite, observée par… ebn Younis*, in: Notices et extraits des manuscrits de la Bibliothèque nationale et autres bibliothèques (Paris) 7e sér. 12/1803–04/16–240, esp. p. 55 (reprint., in: Islamic Mathematics and Astronomy, vol. 24, Frankfurt 1997, pp. 54–278, esp. p. 93), v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 6, p. 207.
[2] v. F. Sezgin, op. cit., vol. 6, p. 207.

Astrolabe

Constructed on the basis of an original made in ca. 340/950 by Aḥmad b. Ḫalaf. According to the inscription, it was made for Ǧaʿfar b. (ʿAlī) al-Muktafī (b. 294/906, d. 377/987), a son of the ʿAbbāsid Caliph al-Muktafī (d. 295/908).
This astrolabe has some similarity with the astrolabe made for, or ascribed to, Pope Sylvester II (380/990, below, p. 94).

Our model:
Brass, engraved.
Mater with bracket and suspension ring with a diameter of 130 mm.
4 discs for the latitudes 21°/24°; 30°/31°; 34°/36°; 37°/39°.
Rete with 17 star pointers.
Double pointer with sights on the back.
(Inventory No. A 2.14)

(Original in la Bibliothèque nationale, Paris, Ge. A. 324)

Gunther, *The Astrolabes of the World*, p. 230, nº 99;
Mayer, *Islamic Astrolabists* p. 37.

Our model:
Diameter: 151 mm.
Thickness: 6 mm.
(Inventory No. A 2.28)

The Astrolabe

of al-Ḫuǧandī

The astrolabe made in 374/984 by the great astronomer and mathematician Abū Maḥmūd Ḥāmid b. al-Ḫiḍr al-Ḫuǧandī[1] (2nd half of the 4th/10th c.) is probably the most beautiful and most interesting among the oldest extant astrolabes. Apart from this, we know of the "comprehensive instrument" (*al-āla aš-šāmila*, below, p. 151) invented by him and of the great sextant with a diameter of about 20 metres which he constructed in Raiy (in the south of modern Tehran) for determining whether the inclination of the Earth's axis is variable or constant (above, p. 25).

Besides the mater and the rete, the astrolabe contains five discs for the latitudes of 21° (Mecca), 27° (al-Qulzum or Hormoz ?), 30° (Cairo), 33° (Baghdad), 36° (Raiy ?) and 39° (Buchara ?). One more disc was made for the latitude 66°17' of a place with the longest possible daylight of 24 hours. One more additional disc was meant for astrological purposes (*maṭraḥ aš-šuʿāʿ*) and for the latitude of Baghdad (33°).

The astrolabe was in the possession of the Moradoff family in 1929. After R. T. Gunther[2] had erroneously described it in 1932 as an astrolabe made in the year 778/1376 by a certain Aḥmad b. al-Ḫiḍr an-Naǧdī, it disappeared into unknown possession. L. A. Mayer[3] could not ascertain anything more about its location in 1956. After some time the instrument reached Paris and was identified correctly by Marcel Destombes.[4] It was in Alain Brieux's collection and later passed into the possession of Ǧāšim al-Ḥumaizī in Kuwait. At present it is said to be in the National Museum of Qaṭar.[5]

[1] v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 5, pp. 307-308; vol. 6, pp. 220-222.

[2] *The Astrolabes of the World*, op. cit., p. 245.

[3] *Islamic Astrolabists*, p. 45 (reprint., op. cit., p. 179).

[4] *Un astrolabe carolingien et l'origine de nos chiffres arabes*, in: Archives internationales d'histoire des sciences (Paris) 15/1962/3–45, esp. p. 16 (reprint in: Islamic Mathematics and Astronomy, vol. 96, 1998, pp. 401–447, esp. p. 418); v. also D.A. King, *Early Islamic Astronomical Instruments in Kuwaiti Collections*, pp. 83–89.

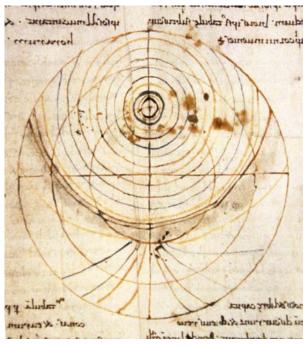
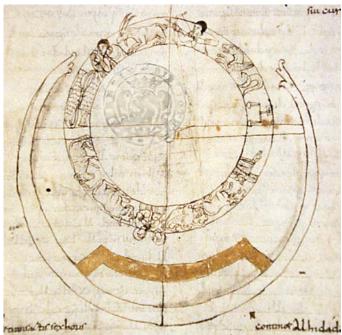
[5] I am indebted to my colleague David King for photographs of the astrolabe.

Astrolabe

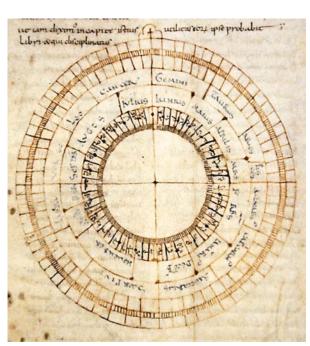
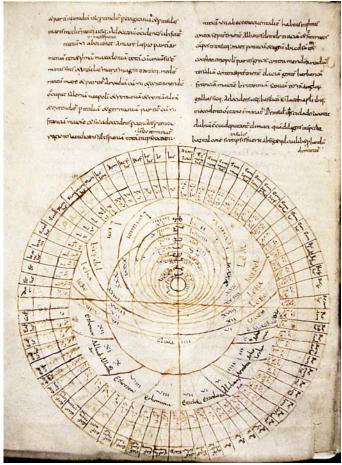
Based on a Catalan model from the 10th century A.D. It is the oldest Latin astrolabe and a copy of an original Arabic astrolabe. What is remarkable is that the Latin lettering represents a transcription of originally Arabic alphabet numbers: on the discs this applies to the numbers of the latitudes, on the mater to the division into twelve hours.

(Original in the Institut du Monde Arabe, Paris)

Our model:
Brass, engraved.
Mater with bracket and suspension ring.
Diameter: 152 mm (with engraving for the latitude of 36°).
2 discs for the latitudes 39°/41°30'; 45°/47°30'.
Rete with 20 star pointers.
Double pointer with sights at the back.
Calendars and shadow square.
Latin lettering.
(Inventory No. A 2.18)

Marcel Destombes, *Un astrolabe carolingien et l'origine de nos chiffres arabes*, in: Archives internationales d'histoire des sciences (Paris) 15/1962/3–45 (reprint in: Islamic Mathematics and Astronomy, vol. 96, Frankfurt 1998, pp. 401–447); David King, *Medieval Astronomical Instruments: A Catalogue in Preparation*, in: Bulletin of the Scientific Instrument Society (Pershore, England) 31/1991/3–7; Paul Kunitzsch and Elly Dekker, *The Stars on the Rete of the so-called ‹Carolingian Astrolabe›*, in: *From Baghdad to Barcelona*. Studies in the Islamic Exact Sciences in Honour of Prof. Juan Vernet, Barcelona 1996, vol. 2, pp. 655–672.

Astrolabe

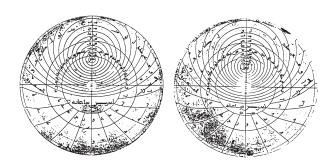
Our model:
Brass, etched.
Diameter: 135 mm, thickness: 5 mm
(Inventary No. A 2.29)
Made by M. Brunold (Abtwil, Switzerland)

Our model was made after the illustrations in the *Sententiae astrolabii* by Lupitus of Barcelona (manuscript in the Bongarsiana Burgerbibliothek Bern, Cod. 196). This work emerged from a partial adaptation and partial free rendering of the Arabic model, the book on the astrolabe by Muḥammad b. Mūsā al-Ḫwārizmī (active under Caliph al-Maʾmūn, ruled 198/813-218/833). Except for two, the 27 star names occurring on the rete are Arabic in Latin script, likewise the names of the lines of unequal hours. It is interesting that the 360 degree scale on the limb is executed threefold: in Arabic alphabet numbers, the same in Latin transcription, and in Latin numbers. On the other hand, the calendar circle (365 days) on the back is engraved only in Arabic alphabet numbers (though not faultlessly). In the manuscript two discs are described (front and back of each for the climates 3, 4, 5 and 6).

v. M. Schramm et al., *Der Astrolabtext aus der Handschrift Codex 196, Burgerbibliothek Bern …,* in : Zeitschrift für Gechichte der arabisch-islamischen Wissenschaften (Frankfurt a.M) 17/2006-7/199-300.

fol. 1a

fol. 2b

Illustrations from Cod. 196,
Burgerbibliothek Bern.
(Fleury? Ottonian, ca. 390/1000)

fol. 3b

fol. 7a

Astrolabe

Based on an original which was allegedly made in France in 380/990 and attributed to Pope Sylvester II.

(Original in the Museo di Storia della Scienza in Florence)

Our model:
Brass, engraved.
Mater with bracket and suspension ring, outer diameter 130 mm.
Rete with 25 star pointers.
2 discs for the latitudes 30°/42° and 36°/38°.
On the back calendars and shadow square.
Double pointer with sights.
(Inventory No. A 2.11)

The original betrays the character of an Arabic astrolabe from the 4th/10th century. The authorship of Pope Sylvester is merely a later conjecture. All numbers and the names of the fixed stars on the spider, on the rim of the mater and on the discs are written in Arabic script. Only the two latitudes 30° and 42° were provided additionally with European numerals. The names of the zodiac signs, the names of the months and the numbers of the degrees on the back are given in Latin or European (Arabic) numerals.

Gunther, *The Astrolabes of the World*, p. 230, no. 101.

Astrolabe

Based on a specimen made in Toledo by Muḥammad b. aṣ-Ṣaffār in 420/1029.

The discs were made for the following cities: Ghana (Ġāna), Sanaʾa (Ṣanʿāʾ), Mecca, Medina, al-Qulzum, Cairo, Cairuan (al-Qairawān), Samarra (Surra-man-rāʾa), Samarqand, Cordova, Toledo, Zaragoza and Constantinople, as well as for the island of Sarandīb (Sri Lanka) and for the northern boundary of the inhabited part of the earth.

(Original in the Staatsbibliothek, Berlin)

Our model:
Brass, engraved.
Mater with bracket and suspension ring with a diameter of 135 mm.
9 discs for the latitudes ca. 6°/10;30°; 14;30°/17;30°; 21;40°/25°; 28°/30°; 32°/34; 20°; 36; 30°/38; 30°; 40°/42°; 45°/66°, and one projection for the latitude of 72°.
Rete with 29 star pointers.
Double pointer with sights on the back.
Calendar circle, shadow square.
(Inventory No. A 2.12)

Fr. Woepcke, *Über ein in der Königlichen Bibliothek zu Berlin befindliches arabisches Astrolabium*, Berlin 1858 (reprint in: Arabic Mathematics and Astronomy, vol. 86, Frankfurt 1998, pp. 1–36); Gunther, *The Astrolabes of the World*, pp. 251–252, no. 116.

Astrolabe

Based on a specimen made in Zaragoza (Spain) by Aḥmad b. Muḥammad an-Naqqāš in 472/1079.

Notre modèle:
Brass, engraved.
Mater with bracket and suspension ring with a diameter of 124 mm.
5 discs for the latitudes 21°/25°; 34°/37°; 35°/38°; 36°/39°; 38°/41°.
Rete with 23 star pointers.
Double pointer with sights.
Calendar circle, shadow square and Arabic inscription on the back.
(Inventory No. A 2.13)

(Original in the Germanisches Nationalmuseum, Nuremberg WI 353)

Mayer, *Islamic Astrolabists* p. 37; *Schätze der Astronomie. Arabische und deutsche Instrumente aus dem Germanischen Nationalmuseum*, Nuremberg 1983, p. 29–31.

Astrolabe

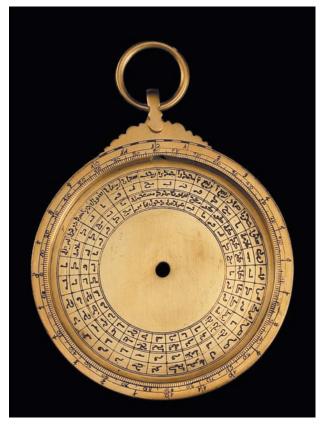
Based on an original made in Valencia (Spain) by Ibrāhīm b. Saʿīd as-Sahlī in 478/1086.

The six discs, made for twelve different latitudes, carry under the Arabic numerals for degrees Roman numbers that were engraved later. The mater contains a 13th engraving for latitude 72°.

(Original made of bronze in the Naturwissenschaftlich-technische Sammlung in Kassel)

Our model:
Brass, engraved.
Mater with bracket and suspension ring with a diameter of 176 mm.
8 discs for the latitudes 13°/19°; 25°/32°; 30°/38°; 32°/35°; 37°/39°; 30°/40°; 38°/41°; 66°/42°.
Rete with 28 star pointers.
Double pointer with sights, length 166 mm.
Arabic inscription on the back: "Constructed by Ibrāhīm, son of Saʿīd, in Valencia".
(Inventory No. A 2.05)

Gunther, *The Astrolabes of the World*, p. 263, no. 121; Mayer, *Islamic Astrolabists,* pp. 51–52; Ludolf von Mackensen, *Die naturwissenschaftlich–technische Sammlung in Kassel*, Kassel 1991, pp. 60–61.

Our model:
Brass, etched.
Diameter: 73 mm.
(Inventory no. A 2.30)

Astrolabe

The astrolabe was made in 613/1216 in Sevilla by Muḥammad b. al-Futūḥ al-Ḫamāʾirī (cf. below, p. 100). The special importance of the astrolabe which we constructed after this original lies in the fact that one of the five discs is prepared for 48°22', i.e. for the latitude of Paris and that, moreover, the spider and the raised rim of the mater (*limbus*, *ḥuǧra*) were provided, for the use of an European, with the Latin rendering of the Arabic names of select fixed stars and, in the place of alphabet numerals, with Arabic numerals. For this purpose the spider and the rim of the astrolabe were ground and freshly inscribed, much later, perhaps after the 16th century. The assumption of a relatively late date of the new legends rests on the fact that the **[99]** outermost circle with a division into 24 parts (2 ×

1-12) presupposes knowledge of the hour angle in Europe. The Latin disc, prepared for 48°22', also seems to have been added later. On the remaining four discs latitudes were added subsequently in Arabic numerals (in the European way of writing), as an aid for reading, which are, however, incorrect. In the following table these are juxtaposed with the correct numbers of the original:

Latitude in original		Latitude in European figures	
a	*b*	*a*	*b*
21°40'	25°	20°	24°
33°30'	37°30'	34°	36°
38°30'	34°30'	37°	33°
35°30'	31°30'	36°	38°
		48°22'	

The inner side of the mater of our model.

At a later point, the astrolabe travelled from Europe to Istanbul. There it was described in all detail and reproduced in five drawings by the Ottoman statesman (*ṣadr-ı aʿẓam*) Ġāzī Aḥmed Muḫtār Paša (1839-1919) in his *Riyāḍ al-Muḫtār, mirʾāt al-miqyās wa-l-adwār maʿa maǧmūʿat al-aškāl* (Cairo 1303, pp. 222-228). The astrolabe, together with other instruments and books, was presented as a gift by Sultan Selīm III (ruled 1203/1789-1222/1807) to the then Mühendisḫāne, the college of engineering and the precursor of today's Technical University in Istanbul[1].

[1] See Kâzım Çeçen, *Astrolab*, in: Lâle (İstanbul) 2/1984/7–11.

Astrolabe

Our model:
Brass, etched.
Diameter: 165 mm.
5 discs for the latitudes:
30°30'/32°30'; 33°30'/34°30';
35°30'/36°30'; 37°30'/38°30'; 39°30'/40°.
(Inventory No. A 2.31)

This astrolabe was made in 626/1228, also by Muḥammad b. al-Futūḥ al-Ḫamā'irī from Sevilla, one of the most prolific and most interesting astrolabe makers. A total of fourteen instruments by him are extant at present.[1] The signs of the zodiac, the names of the months and the rims of the tangents were re-engraved some 100-200 years later with Latin designations. However, the most important feature of the astrolabe lies, as in the previous one, in the engraving on the back of the mater which contains both an Islamic and a Christian calendar, besides a concordance, which H. Sauvaire and J. de Rey-Pailhade described in detail.[2]
Original in the Museum for Islamic Art, Cairo.

Photo of the original, the inner side of the ‹mater› (*umm*).

[1] D.A. King, *A Catalogue of Medieval Astronomical Instruments* (Internet), nº 6/2.
[2] *Sur une ‹mère› d'astrolabe arabe du XIII^e^ siècle (609 de l'Hégire) portant un calendre perpétuel avec correspondance musulmane et chrétienne. Traduction et interprétation*, in: Journal asiatique (Paris), sér. 9, 1, 1893, pp. 5–76, 185–231 (reprint in: Islamic Mathematics and Astronomy, vol. 87). For further literature v. Gunther, *The Astrolabes of the World*, p. 269 ff.; Mayer, *Islamic Astrolabists*, pp. 64–66.

The astrolabe
of the Marine Museum in Istanbul

This is the largest extant astrolabe from before 1000/1600. It is in the Maritime Museum (Deniz Müzesi) at Istanbul and carries the Inventory No. 264. It measures 56 cm in diameter and 1.1 cm in thickness. The astrolabe was constructed in 619/1222 in Damascus for the Aiyubid sultan al-Muʿaẓẓam ʿĪsā b. Abī Bakr b. Aiyūb. Its maker was called ʿAbdarraḥmān b. Sinān al-Baʿlabakkī an-Naǧǧār. The mathematical-astronomical values were contributed by ʿAbdarraḥmān b. Abī Bakr at-Tibrīzī. The silver inlay work was done by as-Sirāǧ ad-Dimašqī. The instrument has two discs, one for the latitudes 30° and 35° and the other for the latitudes 40° and 41°. The obliquity of the ecliptic is based on a value of 23°51'. The rete carries relatively few star positions, altogether twenty. David King[1] called it an important feature of this astrolabe that the rete within the southern ecliptic carries a short equatorial bar as compared to the much longer one below the northern ecliptic; he added that this element appeared here for the first time on the rete of an Arabic astrolabe and recalled certain medieval French instruments; therefore the question arose "whether the basic rete design might have been copied from an instrument brought to the Ayyubid realms during the Crusades." I hope D. King would not today describe this connection any more as he did then, but would rather be inclined to assume that this pattern, on the contrary, reached France through Arabic astrolabes from Syria and through the mediation of the crusaders. Instructive in this respect is the statement by Burkhard Stautz[2] that the form of the star pointers as well as the lower equatorial bar and the knob for turning the rete next to the pointer for the star α CMa recall the forms of early Islamic astrolabes.

[1] *The Monumental Syrian Astrolabe in the Maritime Museum, Istanbul*, in: Erdem (Ankara) 9 (=Aydın Sayılı özel sayısı II)/1996/729–735, esp. p. 731. In connection with the appearance of similar retes on French astrolabes King refers to Emmanuel Poulle, *Un constructeur d'instruments astronomiques au 15ᵉ siècle : Jean Fusoris*, Paris 1963, esp. pp. 19–26 and discs. I and III.

[2] *Die Astrolabiensammlungen des Deutschen Museums und des Bayerischen Nationalmuseums*, p. 43. Some time after I had written these lines I had the opportunity to ask Prof. King if he was still of the same opinion. He said he had revised his opinion shortly after writing the study mentioned and that he had expressed this in his book *The Ciphers of the Monks* (Stuttgart 2001, p. 395). There (note 10) he regrets his earlier assumption and comes to a new one: "Possibly it was inspired by a Syrian astrolabe seen by a French Crusader." Although our positions thus come closer, I consider it more probable that a French Crusader brought an astrolabe with him and that it was imitated in France..

Our model:
Brass, etched;
diameter: 56 cm.
(Inventory No. A 2.24)

Astrolabe

Based on a specimen made in Egypt in 650[1]/1252, by ʿAbdalkarīm al-Miṣrī for the Aiyubid ruler al-Ašraf Muẓaffaraddīn Mūsā.

(Original in the Museum of the History of Science, Oxford)

Our model:
Brass, engraved. Mater with bracket and suspension ring with a diameter of 280 mm. 3 discs for the latitudes 30°/44°; 33°/40°; 36°/66° 30°. Rete with 25 inscribed star pointers. Double pointer with sights on the back. Calendars, quadrants.
(Inventory No. A 2.15)

Gunther, *The Astrolabes of the World,* pp. 233–254, no. 103;
L.A. Mayer, *Islamic Astrolabists,* pp. 29–30 and disc XII.

[1] Not 630 H.

Astrolabe

Based on an original made in in Hama (Ḥamāh, Syria) by as-Sahl al-Asṭurlābī an-Nīsābūrī in 698/1299.

Our model:
Brass, engraved.
Mater with bracket and suspension ring with a diameter of 161 mm.
4 discs (30°/33° and 36°/39° of Arabic origin; 45°/48° and 51° for European latitudes with Latin additions; 42° obviously meant for Rome, not completed).
Rete of silver (spider with figures).
On the back, the alidade with sights, and a pointer attached at right angles.
(Inventory No. A 2.17)

According to the inscription, the astrolabe was made for the Aiyubid ruler al-Malik al-Muẓaffar Maḥmūd Taqīyaddīn. The German astronomer Regiomontanus acquired it prior to 1460, during his stay in Italy, probably in Padua, brought it to Nuremberg and provided it with two additional discs for the latitudes 42° (incomplete), 45°, 48° and 51°. Regiomontanus apparently removed two original discs meant for places south of 30° to make space for the additional discs of the three European cities.

(Original in the Germanisches Nationalmuseum, Nuremberg WI 20)

Gunther, *The Astrolabes of the World,* p. 280, no. 137; Mayer, *Islamic Astrolabists,* pp. 82–83; *Schätze der Astronomie*, pp. 33–35; *Focus Behaim Globus* (Germanisches Nationalmuseum, Exhibition catalogue), Nuremberg 1992, pp. 570–574.

Astrolabe

Our model:
Brass, engraved.
Mater with bracket and suspension ring, outer diameter 155 mm.
4 discs for the latitudes 13°/15°; 13°37'/14°30'; 21°, and 7th climate degree /24° and 6th climate degree.
Rete with 20 star pointers, diameter 130 mm, 22 star positions.
On the back alidade with sights, length 140 mm.
Arabic legend on the back.
(Inventory No. A 2.07)

Based on an original made by al-Malik al-Ašraf in Yemen in 690/1291. Al-Ašraf ʿUmar b. Yūsuf (ruled 694/1295-696/1297), a ruler from the Rasūlid dynasty in Yemen, himself wrote books on the astrolabe and made instruments (with his own hands). On the back of the mater three groups of symbols are marked. The outer ring shows the signs of the zodiac. They are additionally represented in Arabic script too. The second ring carries the symbols of the astrological *arbāb al-wuğūh* and refers to the 36 decans of the zodiac. The signs in the third ring represent the triplicities (*muṯallaṯāt*) of the planets.

(Original in the Metropolitan Museum of Art, New York)

Gunther, *The Astrolabes of the World,* p. 243, no. 109; Mayer, *Islamic Astrolabists,* pp. 83–84; David King, *The Medieval Yemeni Astrolabe in the Metropolitan Museum of Art in New York City*, in: Zeitschrift für Geschichte der arabisch–islamischen Wissenschaften 2/1985/99–122.

Astrolabe

Based on an Arabic model, probably dating back to the 7th/13th century.

(Original in the British Museum in London)

Gunther, *The Astrolabes of the World*, p. 238, no. 105.

Our model:
Brass, engraved.
Mater with bracket and suspension ring,
diameter 150 mm.
3 discs for the latitudes
21°/24°; 27°/33°; 30°/31°.
Rete with 29 star pointers,
diameter 120 mm.
The back carries a double pointer
with sights, length 140 mm.
(Inventory No. A 2.06)

Astrolabe

Our model:
Brass, etched.
Mater with bracket and suspension ring, outer diameter 120 mm.
2 discs for the latitudes 33°/36° and 72°.
(Inventory No. A 2.33)

Replica of one of the five extant astrolabes made towards the end of the 9th/15th century by Šamsaddīn Muḥammad Ṣaffār.
The original of our reconstruction is in the Museum for Islamic Art, Cairo;[1] it is dated 884/1477. The other four instruments by Muḥammad Ṣaffār are in Cambridge, Oxford (2 specimens) and Brussels.[2]

[1] See G. Wiet, *Épigraphie arabe de l'exposition d'art persan du Caire,* in: *Mémoires présentés à l'Institut d'Egypte* (Cairo) 26/1935/p. 19.
[2] See Mayer, *Islamic Astrolabists*, pp. 75–76.

Astrolabe

Based on the original made by Muḥammad Muqīm al-Yazdī for Shah ʿAbbās II of Persia in the year 1057/1647. (Original in the Evans Collection, Museum of the History of Science, Oxford)

Our model:
Brass, engraved.
Mater with bracket and suspension ring, diameter 30 cm (second specimen with a diameter of 45 cm).
In the mater the coordinates of 46 cities between Baghdad and Balḫ (Balkh) are engraved, whose longitudes are counted from a prime meridian that lies 28°30' to the west of Toledo, or 17°30' to the west of the Canary Islands.
4 discs (the original has 5) for the latitudes 23°/43°; 29°/30°; 33°/37°; 36°/37°.
Rete with 46 star pointers inscribed with the names of stars in the Persian language, with which the astrolabe allows extensive measurements of time.
Double pointer with sights on the back.
Sine quadrant, zodiacal quadrant and two shadow squares.
(Inventory No. A 2.16)

Gunther, *The Astrolabes of the World,* pp. 132–135, no. 18; Mayer, *Islamic Astrolabists,* p. 208.

An Ottoman
Astrolabe

Our model:
Brass, etched.
Diameter 183 mm.
4 discs.
Alidade with sights.
(Inventory No. A 2.32)

The instrument was made in the year 1091/1680 for a certain Sulṭān b. Aʿẓam b. Bāyazīd, probably a descendant of the Ottoman Sultan Bāyazīd II (d. 918/1512). It has four discs for 21° (Mecca), 30° (Cairo), 34° (Damascus), 36° (Aleppo), 41° (Istanbul) and 42° (Edirne). The inner surface of the mater is empty. The back carries a sine quadrant and a tangent quadrant.

The original is in the Museum for Islamic Art in Cairo.

Astrolabe

Our model:
Brass, engraved.
Diameter 90 mm. 4 discs.
Rete with 21 star names.
Double pointer with sights.
The back carries a calendar
with zodiac signs and shadow squares.
(Inventory No. A 2.20)

In the possession of the Institute, made in Iran (Esfahan ?) in the year 1118/1706. The four discs are meant for the latitudes 21°10', 21°10' (a second time), 22°40' and 39°15'. The latitudes of 36 Persian cities are engraved on the inner side of the mater. Most of these values are incorrect. Thus our model forms an interesting example of the period of decadence in the use of the astrolabe in the Arabic-Islamic area, when people were no longer able to use it as an instrument for astronomical observations.

Astrolabe

Based on a Spanish-Gothic instrument from the 14th century A.D.

"The European instrument is obviously closely related to the Arabian area. Thus the star names, with a few exceptions, are of Arabic origin. Even the Latin name Cadens = "plunging" (eagle) is a reference to an Arabic constellation" (M. Brunold).

Original in the Society of Antiquaries, London.

Our model:
Brass, engraved.
Gothic numerals.
Mater with bracket and suspension ring, outer diameter 120 mm.
2 discs for the latitudes 36°/40° and 44°/48°.
The rete with arabesques and quatre foil ornament shows 17 star positions.
Ruler with a radius of 60 mm.
On the back, ecliptic circle and calendar circle, with a shadow square and a diagram for determining the weekday at the beginning of the year.
Double pointer with sights.
Made by M. Brunold (Abtwil, Switzerland).
(Inventory No. A 2.08)

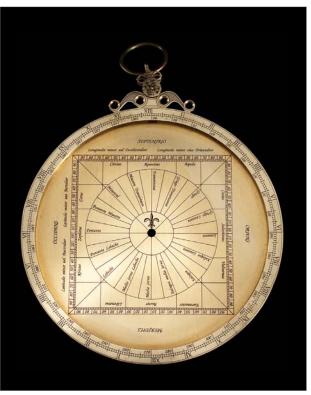
Gunther, *The Astrolabes of the World*, pp. 306–309, no. 162.

Astrolabe

Made by Martin Brunold (Abtwil, Switzerland) in the style of a European astrolabe of ca. 1500.

Our model: Brass, engraved. Mater with bracket and suspension ring, diameter 100 mm with horizontal coordinates for the latitude of 48°. Without discs. Rete with 14 star positions and an hour scale for which there was no space on the narrow rim of the instrument. Ruler in the radius of 50 mm, back with ecliptic circle and calendar circle, shadow square, diagram of the unequal hours and double pointer with sights.
(Inventory No. A 2.09)

Cf. Gunther, *The Astrolabes of the World*, pp. 324–325, no. 173.

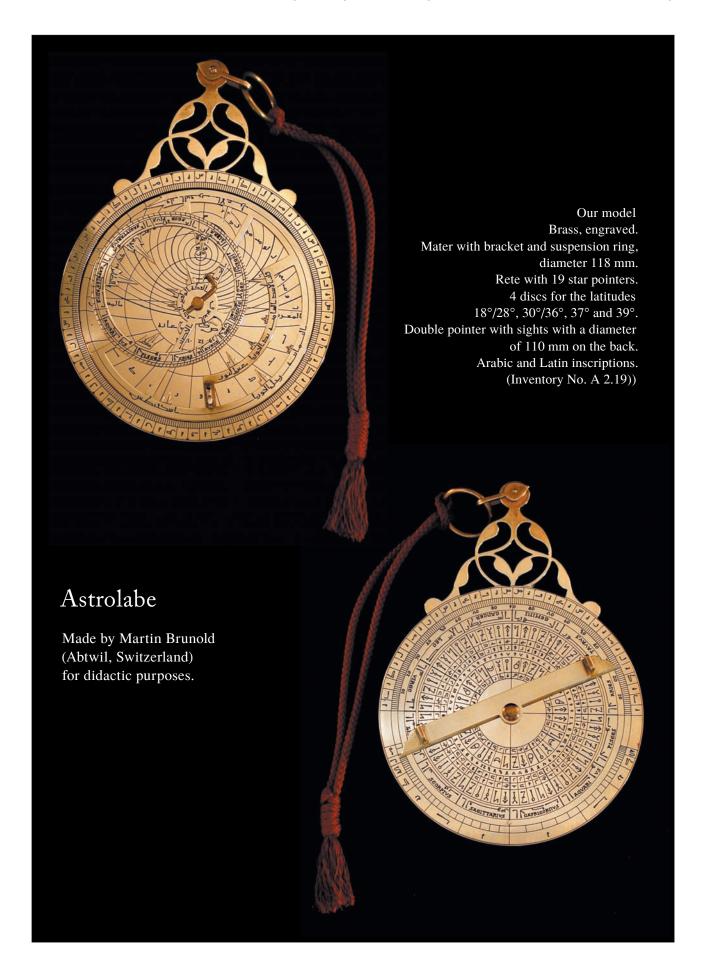
Astrolabe

Made on the basis of a prototype manufactured in the workshop of Gualterus Arsenius around 1570. This was in the collection Gréppin and was auctioned in Paris in 1980 together with the Linton collection.

Our model:
Brass, engraved.
Mater with bracket and suspension ring, outer diameter 156 mm.
3 discs for the latitudes 39°/42°, 45°/48° and 51°/54°.
Rete with 37 star-positions, intertwined ribbons and the "form of an angel" in the centre. Double pointer with sights.
Back with az-Zarqālī-projection with 2.5° grid and 25 star positions. Over these a horizontal bar rotates with the twilight border, together with a cursor and brachiolus.
4 × 90° division on the rim. Latin lettering.
(Inventory No. A 2.10)

Detailed description in a brochure by Martin Brunold (Abtwil, Switzerland), the maker of our model.

Astrolabe

Made on the basis of on an instrument manufactured around 1600 A.D. by Erasmus Habermel.

On the back "the disc of az-Zarqālī" is reproduced. The original, on which our specimen is modelled, is now in the Museum of the History of Science, Oxford.

Gunther, *The Astrolabes of the World*, pp. 453–456, no. 278.

Our model:
Brass, engraved.
12-cornered mater with bracket and suspension ring, diameter 210 mm.
3 discs for the latitudes 39°/42°, 45°/48° and 51°/54°.
Rete with 30 star positions.
Double pointer with sights, length 210 mm.
On the back a horizontal bar with a cursor and brachiolus.
(Inventory No. A 2.04)

Made by Martin Brunold (Abtwil, Switzerland).

Our model
Brass, engraved.
Mater with bracket and suspension ring, diameter 118 mm.
Rete with 19 star pointers.
4 discs for the latitudes 18°/28°, 30°/36°, 37° and 39°.
Double pointer with sights with a diameter of 110 mm on the back.
Arabic and Latin inscriptions.
(Inventory No. A 2.19))

Astrolabe

Made by Martin Brunold
(Abtwil, Switzerland)
for didactic purposes.

THE UNIVERSAL DISC

This instrument, known in Europe under the name saphaea (*aṣ-ṣafīḥa az-zarqālīya*), “consists only of a single disc on which the celestial equator and the ecliptic with their parallel circles and vertical circles are projected from the first point of Aries or that of Libra upon the plane of the solstitial colure. Since the first point of Aries or that of Libra constitute at the same time the east or the west points of every horizon, the disc is valid for all latitudes. The horizon itself is projected through a straight line passing through the centre of the projection; the straight line is represented by a ruler, movable around the centre and provided with divisions. By means of the division of degrees on the rim of the disc the ruler can be assigned any location according to the position occupied by the horizon on the celestial sphere in relation to the equator. The back is usually that of the common astrolabe, except that there is a small circle on it through which the orbit of the Moon can be represented.”

Josef Frank, *Zur Geschichte des Astrolabs*, Erlangen 1920, p. 32 (reprint in: Islamic Mathematics and Astronomy, vol. 35, pp. 1–33, esp. p. 32). José Millás Vallicrosa, *Un ejemplar de azafea árabi de Azarquiel,* in: Al-Andalus 9/1944/111–119 (reprint in: Islamic Mathematics and Astronomy, vol. 40, pp. 233–245).

Universal Disc

Based on an original made 650/1252, in Murcia (Spain), by Muḥammad b. Muḥammad b. Huḏail.

(Original in the Observatorio Fabra, Barcelona)

Our model:
Brass, etched.
Diameter 185 mm.
Length of the alidade 185 mm.
Ruler with division into degrees, length 165 mm.
Thickness 3 mm.
Arabic alphabet numerals.
(Inventory No. A 2.03)

Our model:
Brass, etched.
Diameter 185 mm.
Length of the alidade 185 mm.
Ruler with divisions into degrees, length 165 mm.
Arabic alphabet numerals.
(Inventory No. A 2.34)

Universal Disc

(*ṣafīḥa*)

by Muḥammad b. Futūḥ al-Ḫamāʾirī

It is one of several universal discs, called *ṣafīḥa zarqālīya* or *šakkāzīya*, made by Muḥammad b. al-Futūḥ al-Ḫamāʾirī. He made it in Sevilla in the year 613/1216. It has a diameter of ca. 216 mm. 33 names of fixed stars are engraved on it.
In the first half of the 19th century, the instrument was acquired by Almerico da Schio in Valdagno near Vicenza (Veneto). Now it is in the possession of the observatory (Osservatorio Astronomico) in Rome (No. 694 II).

See A. da Schio, *Sur deux astrolabes arabes*, in: Atti del IV Congresso Internazionale degli Orientalisti tenuto in Firenze… 1878, vol. 1, Florence 1878, pp. 367–369 (reprint in: Islamic Mathematics and Astronomy, vol. 86, Frankfurt 1998, pp. 177–179); idem, *Di due astrolabi in caratteri cufici occidentali trovati in Valdagno (Veneto)*, Venice 1880 (reprint in: Islamic Mathematics and Astronomy, vol. 86, pp. 194–272); R.T. Gunther, *The Astrolabes of the World,* pp. 270–273; Mayer, *Islamic Astrolabists and Their Works*, Geneva 1956, p. 65 (reprint in: Islamic Mathematics and Astronomy, vol. 96, Frankfurt 1998, p. 199).

Diameter: 185 mm. Thickness: 3 mm.
Calendars and sine lines. Roman numerals.
(Inventory no. A 2.02)

Universal Disc

Reconstruction after the illustration and description in the *Libros del saber de astronomía*, a collection of texts compiled by several scholars in Andalusia at the behest of King Alfonso X of Castilia.

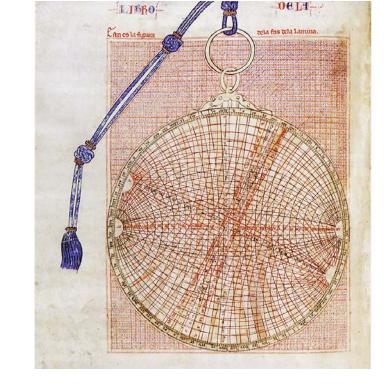
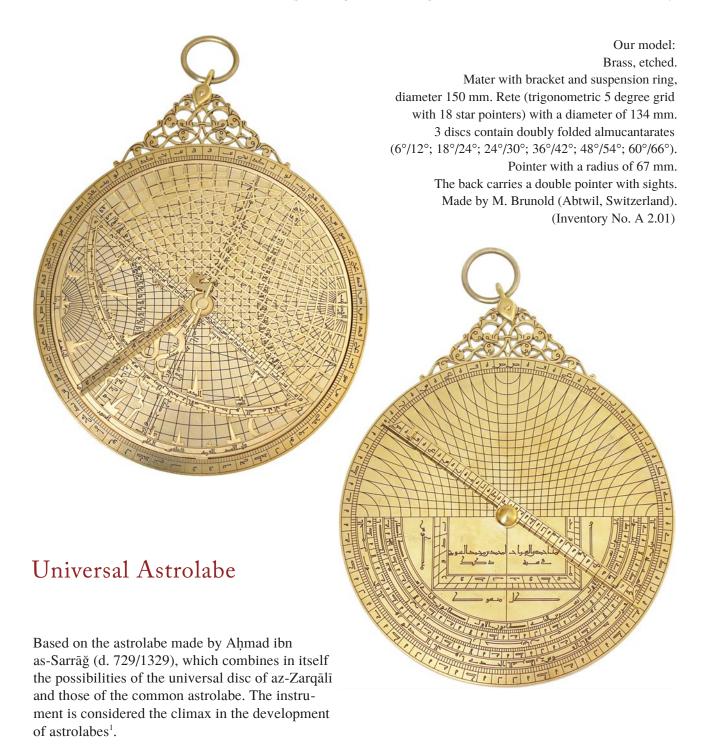



Illustration of the universal disc of az-Zarqālī from the *Libros del saber de astronomía*.

Our model:
Brass, etched.
Mater with bracket and suspension ring, diameter 150 mm. Rete (trigonometric 5 degree grid with 18 star pointers) with a diameter of 134 mm.
3 discs contain doubly folded almucantarates (6°/12°; 18°/24°; 24°/30°; 36°/42°; 48°/54°; 60°/66°).
Pointer with a radius of 67 mm.
The back carries a double pointer with sights.
Made by M. Brunold (Abtwil, Switzerland).
(Inventory No. A 2.01)

Universal Astrolabe

Based on the astrolabe made by Aḥmad ibn as-Sarrāǧ (d. 729/1329), which combines in itself the possibilities of the universal disc of az-Zarqālī and those of the common astrolabe. The instrument is considered the climax in the development of astrolabes[1].

(Original in the Benaki-Museum in Athens)

[1] Another three astrolabes, without the combination with a universal disc, by Ibn as-Sarrāǧ, are extant: 1. Hyderabad, Salar Jung Museum (623 H/1226): 2. Rampur (626/1228); 3. London, Greenwich, National Maritime Museum (628/1230). *The Planispheric Astrolabe*, London 1976, pp. 44–45; Sreeramala R. Sarma, *Astronomical Instruments in the Rampur Raza Library*, Rampur 2003, pp. 25–33. Gunther, *The Astrolabes of the World,* pp. 285–286, no. 140; Mayer, *Islamic Astrolabists,* pp. 34–35; David King, *On the Early History of the Universal Astrolabe in Islamic Astronomy and the Origin of the Term ‹Shakkāzīya› in Medieval Scientific Arabic*, in: D.A. King, *Islamic Astronomical Instruments*, Variorum Reprints, London 1987, no. VII.

Spherical Astrolabe

According to the present state of our knowledge of the history of astronomy, the spherical astrolabe seems to have been produced for the first time in the Arabic-Islamic period. The astronomers of the Arabic-Islamic area adapted devices like the armillary sphere, the celestial globe or the simple flat astrolabe directly or indirectly from the Greeks and maintained a continuous development and improvement of these instruments. The spherical astrolabe, on the other hand, seems to be one of the inventions of the new Arabic-Islamic culture. However, in Arabic sources the spherical astrolabe is not infrequently mistaken for the armillary sphere and therefore Ptolemy is mentioned as its inventor, as in the *Fihrist*[1] of Ibn an-Nadīm (d. 380/990). A reference by al-Bīrūnī allows the assumption that Ǧābir b. Sinān al-Ḥarrānī[2] (2nd half of the 3rd/9th c.) was the inventor of the spherical astrolabe. In his *Kitab Istīʿāb al-wuǧūh al-mumkina fī ṣanʿat al-asṭurlāb*,[3] al-Bīrūnī states: "I have seen an astrolabe which Gâbir ben Sinân al Ḥarrânî had made. The spider is not needed here, because he had drawn the horizon and the parallels of altitude on the sphere and bored holes in the latter corresponding to the latitude on the two quadrants diametrically opposite to each other. Then he had attached 3 rings which had the same size as the largest circles on the sphere: one of them, the equator, was affixed to the other equator on the sphere, the other one was the zodiac which is inclined at the equator by the same amount as the zodiac against the equator; the third was the circle which went through the 4 poles which are on the sphere; i.e. that which goes through the poles of the first two circles. In that third circle he bored 2 holes at the poles of the equator and put an axis into them and into the holes that are to be taken into consideration for the latitude on the sphere, and attached a clamping screw to this axis."[4]

This instrument is seldom dealt with in contemporary research on the history of Arabic-Islamic astronomy; in 1846 Louis-Amélie Sédillot was the first to make it known through the French translation of the relevant part of the *Ǧāmiʿ al-mabādiʾ wa-l-ġāyāt* by Abu l-Ḥasan al-Marrākušī (2nd half of the 7th/13th c.).[5] In the second decade of the 20th century, C. A. Nallino gave a short description of the instrument in his article *Asṭurlāb* in the *Enzyklopaedie des Islam*.[6] A detailed and excellent treatment of the subject was provided by Hugo Seemann and Theodor Mittelberger in their study *Das kugelförmige Astrolab nach den Mitteilungen von Alfons X. von Kastilien und den vorhandenen arabischen Quellen* (1925). Without their descriptions and drawings it would not have been possible to construct our models. The instruments discussed here are those of:

1. Abu l-ʿAbbās al-Faḍl b. Ḥātim an-Nairīzī (d. at the beginning of the 4th/10th c.).
2. Abu r-Raiḥān Muḥammad b. Aḥmad al-Bīrūnī (d. 440/1048).
3. al-Ḥasan b. ʿAlī al-Marrākušī (7th/13th c.).
4. The instrument shown in the *Libros del saber de astronomía*, written jointly by many scholars on the order of Alfonso X of Castilia (b. 1221, d. 1284 A.D.).

[**121**] Besides the detailed description of the four spherical astrolabes with the drawings of their "spiders" (*ʿanqabūt*), the respective instruments of the above-mentioned Ǧābir b. Sinān al-Ḥarrānī and of Qusṭā b. Lūqā[7] (3rd/9th c.) are also discussed in this study.[8]

Some information on the "principle" and "general description" of the instrument is extracted from

[1] ed. G. Flügel, Leipzig 1872, p. 267; v. Hugo Seemann, with the collaboration of Th. Mittelberger, *Das kugelförmige Astrolab nach den Mitteilungen von Alfons X. von Kastilien und den vorhandenen arabischen Quellen*, Erlangen 1925 (Abhandlungen zur Geschichte der Naturwissenschaften und der Medizin. Heft VIII), p. 3 (reprint in: Islamic Mathematics and Astronomy, vol. 88, Frankfurt 1998, pp. 359–431, esp. p. 365).

[2] v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 6, p. 162.

[3] MS Istanbul, Süleymaniye Kütüphanesi, coll. Carullah 1451, fol. 38a.

[4] H. Seemann, Th. Mittelberger, op. cit., pp. 43–44 (reprint, op. cit., pp. 405–406).

[5] *Mémoire sur les instruments astronomiques des Arabes*, Paris 1844, pp. 142 ff. (reprint in: Islamic Mathematics and Astronomy, vol. 42, pp. 45–312, esp. pp. 188 ff.).

[6] vol. 1, Leiden and Leipzig 1913, German edition, p. 522.

[8] v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 6, pp. 180–182.

[7] H. Seemann, Th. Mittelberger, op. cit., pp. 40, 46–49 (reprint, op. cit., pp. 402, 408–411).

the study by the two scholars Seemann and Mittelberger[9]:

"The most graphic device with which it is possible to represent and define numerically the daily motions of the celestial sphere against the terrestrial system of horizontal coordinates of the parallels of altitude and the azimuthal circles consists in letting an appropriately cut out hollow hemisphere, on which a number of the better known stars and the zodiac are inscribed, rotate upon a firmly fixed sphere in which the system of horizontal coordinates and perhaps also other systems of lines are inscribed."

Fig. 1

Fig. 2

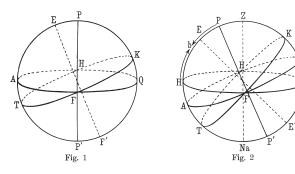



Fig. from H. Seemann, Th. Mittelberger, *Das kugelförmige Astrolab*, p. 2 (reprint p. 364).

" … On a firmly fixed sphere the horizon is drawn as a large circle; its poles are zenith Z and nadir Na. It divides the sphere into two halves. On the one upper hemisphere the system of the parallels of altitude, which are parallel to the horizon, and the system of the azimuthal circles (or vertical circles), which are perpendicular to the horizon, are inscribed, as well as the meridian circle …"

"Of the movable celestial sphere, for reasons of greater clarity of the device, generally only one half is executed as a thin, hollow hemisphere (hemispherical bowl), which is called the spider."

"In order to obtain a device with which it is possible to undertake the necessary demonstrations and measurements, the spider and the sphere are combined in the following way. (This is demonstrated graphically in Fig. 2 for the geographical latitude b). The spider is placed upside down upon the sphere so that it covers, with its inner concave area, over half of the sphere's surface area. A rod, representing the celestial axis PP', is inserted through the pole, bored for this purpose, of the equator P or P' on the spider and through two holes G and G', made diametrically opposite on the meridian circle of the sphere (corresponding to the given geographical latitude), so that either G and P or G and P' come into congruence. A whole series of such pairs of holes can be made on the sphere, thus making the device practible for different geographical latitudes."[10]

The advantages and disadvantages in the use of the spherical astrolabe over the flat astrolabe are summed up by al-Bīrūnī[11] as follows: "I maintain that, even if this one (i.e. the spherical) is easily manufactured and that which we have discussed before is not needed, the flat astrolabe still obviously has advantages; thus the ease with which it can be taken along while travelling. Furthermore, it can frequently be stored at places where this is not possible with the spherical one, e.g. in the sleeves, the bosom of garments, the inside of boots, the appendages of girdles etc. At the same time it withstands strong knocks easily which is not the case with the one shaped like a sphere even with the slightest blow, knock or fall. On the other hand, the representation of that which is on the sphere and the form of the motion taking place on it are more easily visualised on the spherical astrolabe."

[**122**] Of our four spherical astrolabes made after the drawings and explanations of Seemann and with reference to originals, the one by Nairīzī does not have an alidade. Al-Bīrūnī describes two variants, one with and one without an alidade; al-Marrākušī does not allude to the existence of an alidade and the *Libros del saber de astronomía* contain the description of an alidade which—leaving aside a missing element—resembles al-Bīrūnī's second variant. The sighting of the stars was done with the instruments described by an-Nairīzī and al-Marrākušī and with al-Bīrūnī's second variant by observing the heavenly bodies through two holes situated opposite each other which lead through the two poles of the sphere that represent the North and South pole. The Sun's altitude was measured, according to the same three sources, by employing a gnomon, placed at the north or south point of the horizon. It could be moved in the recess by rotating the sphere.

[9] *Das kugelförmige Astrolab,* p. 2 (reprint, op. cit., p. 364).

[10] Ibid., pp. 2–3 (reprint pp. 364–365).

[11] See his *Istīʿāb al-wuǧūh al-mumkina*, translated by H. Seemann and Th. Mittelberger, op. cit., p. 41 (reprint, op. cit., p. 403).

Al-Bīrūnī's version with an alidade, which also appears in our replicas, is insofar more practical since the arc of the circle divided into 180° is reinforced by another arc of the circle which is affixed to it perpendicularly. Thus it is guaranteed that the concave area of the alidade remains in contact with the convex side of the spider and that the observation will not be affected; we cannot expect this with the alidade described in the *Libros del saber de astronomía*.

This type of alidade possesses a certain advantage over the others. However, it has disadvantages because of its sights which consist of metal strips that are affixed to the ends of the alidade and stand upright, parallel to one another beyond the radius of the spider. Most of all because of this inconvenient alidade, the spherical astrolabe will have appeared disadvantageous to those astronomers who desired to carry in their travels an easily manageable device, as the one described by al-Bīrūnī.

The original instrument, preserved from the year 885/1480, testifies not only through its excellent alidade to the fact that the spherical astrolabe went through a further development in the Arabic-Islamic area even after the 7th/13th century. According to our present knowledge this type of instrument seems not to have attracted the attention of European astronomers. In any case, leaving aside Islamic Andalusia, no specimen made in Europe is known to us so far, nor any Latin or Hebrew translation of an Arabic treatise on the spherical astrolabe. *The Libros del saber de astronomía* too do not seem to have exercised any further influence.

1.

The spherical astrolabe

by an-Nairīzī
(early 4th/10th c.)

Our model:
Brass, etched,
diameter: 17 cm.
(Inventory No. A 1.08)

The book dealing with this type of astrolabe, *Kitāb fi l-ʿAmal bi-l-asṭurlāb al-kurawī* by an-Nairīzī, is preserved in a single manuscript.[1] H. Seemann[2] considers this treatise "the best and most detailed" amongst the other known Arabic texts on this topic.
In the movable spider set up on the sphere, only the northern celestial sphere is taken into account. "At the ecliptic pole of the spider the 'largest kursî' is affixed. This is probably an openwork circular disc, which is made fast around the ecliptic pole of the spider, as in the case of the one by Alfonso of Castilia (below, p. 129). One more, the so-called 'small *kursî*', is affixed at the pole of the spider's equator and is probably also an openwork circular disc, like the large *kursî* at the ecliptic pole. The so-called 'suspension' (Arabic *ʿilâqa*) is put on it, which is essentially probably nothing more than the broadened end of the celestial axis, which … is called the 'nail'; perhaps with the suspension meaning the celestial axis itself …"
"For measuring altitudes, a device is affixed on the circular rim of the spider; this device is called *mağrâ* in the text (we call it altitude quadrant). It is a quadrant strip with a recess in the middle that serves as a groove. The strips on both the sides of the recess are divided into 90°. At the 90° point of division, at one end of the quadrant, the so-called '*kursî* of the altitudes' is situated, an [**124**] attachment on which probably a suspension ring is affixed, with which the astrolabe was suspended while altitudes were measured, just as in the astrolabe of Alfons. No mention is made of an alidade.— On the method of measuring altitudes, tasks 1 and 31 (from Nairīzī's book) give information which we wish to discuss here because of the context. The spider is made fast in the pole of the

[1] Spain, Escurial 961/6 (fol. 45a–68b, 863 H.), v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 6, p. 192.
[2] *Das kugelförmige Astrolab,* p. 32 (reprint, op. cit., p. 394).

A: zodiac,
B: altitude quadrant,
C: equator, without division (in the figure drawn arbitrarily as a small circle, because of the absence of more precise data),
D: connecting pieces,
K_1, K_2, K_3: three so-called *kursî*,
G: gnomon for measuring altitudes, affixed to the sphere and moving in the recess between the two altitude quadrants,
R: suspension ring for measuring altitudes

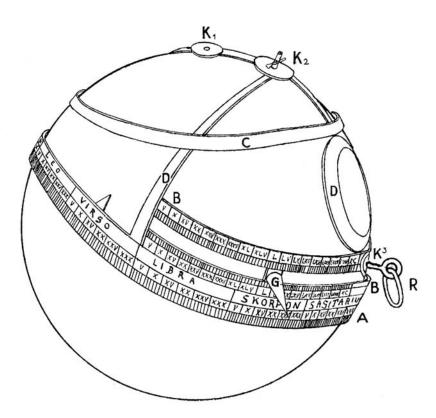



Illustration from H. Seemann, Th. Mittelberger, *Das kugelförmige Astrolab,* p. 68 (reprint, p. 430).

ecliptic on the poles of the horizon on the sphere, so that the circular rim of the spider, to which the altitude quadrant is affixed, is congruent with the horizontal circle of the sphere. … For determining of the Sun's altitude a gnomon is affixed to the north or south point of the horizon, which can be moved in the groove by rotating the sphere. Then the astrolabe is aligned to the Sun by holding it suspended freely from the *kursî* of altitude and the gnomon is shifted until it does not throw a shadow and the sunlight falls into the cavity of the gnomon. To determine the altitudes of stars, the sights are aligned on the star through the holes situated diametrically opposite to each other at the north and south points of the horizon, whereby one of the two holes moves in the groove just like the gnomon during the observation of the Sun's altitude."[3]

Our model was made after the drawing and explanations of H. Seemann[4].

[3] H. Seemann, Th. Mittelberger, *Das kugelförmige Astrolab,* pp. 35-36 (reprint, pp. 397-398).

[4] Ibid., p. 68 (reprint, p. 430).

2.

The spherical astrolabe

by al-Bīrūnī
(d. 440/1048)

Our model:
Brass, etched,
diameter: 17 cm.
(Inventory No. A 1.09)

In his “Comprehensive treatment of the possible methods while manufacturing the astrolabe” (*Istīʿāb al-wuǧūh al-mumkina fī ṣanʿat al-asṭurlāb*), al-Bīrūnī gives a description of the spherical astrolabe which was translated after the Leiden manuscript[1] into German.[2] Here, we cite his statements on the southern hemisphere and the device for measuring altitudes: “The southern spherical astrolabe differs from it [the northern one] through the spider, that is to say, it differs to the extent that half the equator, which lies on the hemisphere of the spider, is taken from the first point of Aries up to the first point of Libra, and that we mount on the southern spherical astrolabe the stars of the southern latitude (i.e. of negative latitude). The axis we insert through the celestial pole of the spider and through the holes that are under the horizon. Then the procedure is the same with both astrolabes. Among astrolabe makers there are some who are satisfied with that.”

“Moreover, we also mention an apparatus for measuring altitudes. Whosoever wishes to measure the altitude must suspend the astrolabe on the zenith so that the parallels of altitude are parallel to the Earth’s horizon. Then on the degree of the Sun, we set up a small gnomon which stands

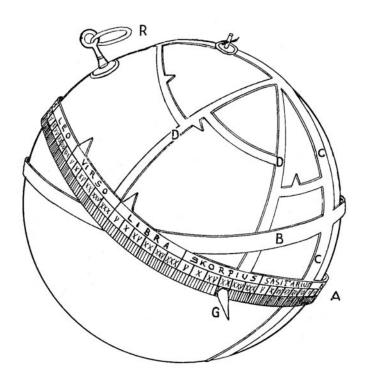
[1] Bibliotheek der Rijksuniversiteit, Or. 591 (p. 47–175, 614 H.), v. F. Sezgin, *Geschichte des arabischen Schrifttums,* vol. 6, p. 268.
[2] H. Seemann, Th. Mittelberger, *Das kugelförmige Astrolab,* pp. 40–44 (reprint, pp. 402–406); we also consulted the Istanbul manuscript, Carullah 1451, fol. 36b ff.

A: zodiac,
B: equator, as a complete great circle, without divisions,
C: solstitial colure as a complete great circle, without divisions,
D: connecting pieces,
G: gnomon for determining the Sun's altitude,
R: suspension ring, fastened to the sphere at the zenith, for determining the Sun's altitude.

Illustration from H. Seemann, Th. Mittelberger, *Das kugelförmige Astrolab,* p. 69 (reprint p. 431).

perpendicularly [**126**] on the sphere and on the spider, and rotate it, i.e. the degree of the Sun with the gnomon, which is done by rotating the spider until the gnomon shades itself and does not throw a shadow upon another spot of the sphere but only upon itself. Then the ascendant coincides with the eastern horizon. It is more convenient to operate this arrangement on the sphere than on the spherical astrolabe."[3]

After this al-Bīrūnī describes the use of the spherical astrolabe for measuring the altitude of the Sun or that of a star by means of the above-mentioned alidade (above, p. 122): "Amongst the artists [i.e. the astrolabe makers] there are some who make an arc of the circle, whose inner surface touches the convex side of the spider; on its two ends on the convex side they attach a semicircle which is divided into 180 equal parts and then they mount that arc on the axis of the astrolabe, so that its inner surface touches the outer surface of the spider. At the end of the axis an alidade is fastened whose pointer touches the circumference of the semicircle, which is the circle on which the altitude is measured."[4]

Our model was made after the drawing and explanations by H. Seemann,[5] while using the original Arabic text.

[3] H. Seemann, Th. Mittelberger, op. cit., p. 43 (reprint p. 405).

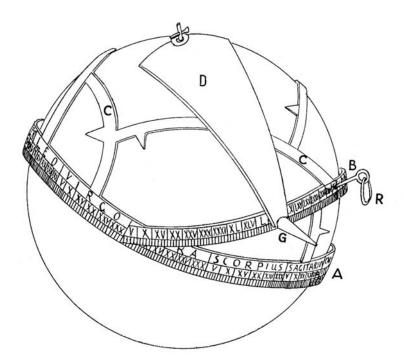
[4] Ibid.

[5] Ibid. p. 69 (reprint, op. cit., p. 431).

3.
The spherical astrolabe

of al-Marrākušī
(2nd half of the 7th/13th c.)

Our model:
Brass, etched,
diameter: 8 cm.
(Inventory No. A 1.10)

Al-Marrākušī describes the instrument in his book *Ǧāmiʿ al-mabādiʾ wa-l-ġāyāt fī ʿilm al-mīqāt*;[1] a French translation of this passage is to be found in L. A. Sédillot's work[2] and explanations to it in the study by H. Seemann.[3] There we read: "For using the astrolabe at different latitudes, holes are bored into the sphere in the well known manner. According to al-Marrâkushî it is advisable to bore holes corresponding to each of the parallels of altitude drawn on the sphere at their intersections with the meridian quadrant from the zenith up to the north point of the horizon and at the points of the sphere which lie diametrically opposite to these. Then the number of pairs of holes corresponding to the latitudes agrees with the number of parallels of altitude inscribed on the sphere."
"Al-Bīrūnī's qualifying remark on discontinuing the hour lines when the astrolabe is prepared for use in various latitudes is not to be found in the work of al-Marrâkushî nor of Alfons …"
"Al-Bīrūnī's qualifying remark on discontinuing the hour lines when the astrolabe is prepared for use in various latitudes is not to be found in the work of al-Marrâkushî nor of Alfons …"
"The apparatus for measuring the altitude is again of a different kind than in the cases discussed so far. The measuring apparatus proper is in the form of a very small, isosceles spherical triangle; its concave area touches the convex surface of the spider. In Arabic, it is called *ṣafîḥa* (disc). The line bisecting it from the apex up to the middle of the base should be equal to a quadrant of a great circle on the spider. Into the two end points [**128**] of this bisecting line, that is to say, into the apex A and the middle of the base B, holes are bored of the same size as the holes present on the sphere

[1] Facsimile edition,Frankfurt: Institut für Geschichte der Arabisch–Islamischen Wissenschaften, 1984, vol. 2, pp. 8–14.
[2] *Mémoire sur les instruments astronomiques des Arabes*, pp. 142 ff. (reprint, pp. 188 ff.).
[3] *Das kugelförmige Astrolab,* pp. 44–46 (reprint, pp. 406–408).

A: zodiaque,
B: equator as half of a great circle with divisions,
C: connecting pieces,
D: isosceles spherical triangle pivoted at the base line to the pole of the equator so that the apex can be moved along the equator
G: gnomon for altitude measurement
R: suspension ring for altitude measurement..

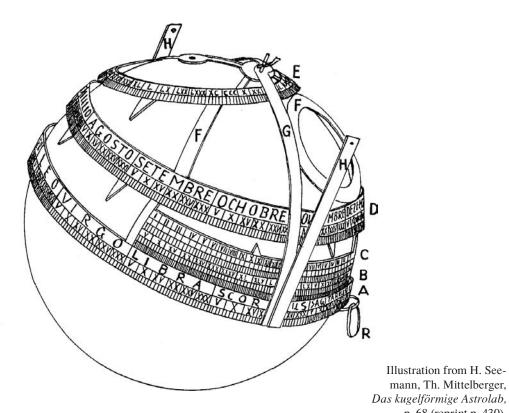
H. Seemann, Th. Mittelberger, *Das kugelförmige Astrolab,* p. 69 (reprint p. 431).

for the latitudes. The *ṣafîḥa* is pivoted through the hole at the middle of the base to the pole of the equator of the spider. Into the hole at the apex of the *ṣafîḥa* a small cylindrical gnomon is inserted, which is always aligned to the centre of the sphere. The apex of the *ṣafîḥa* with the gnomon then glides above half of the equator, which is divided into 180 degrees, on the spider. For suspending the astrolabe correctly while measuring altitudes by means of the apparatus discussed above, a suspension device is attached at the 90th division of the equator on the spider. Al-Marrâkushî does not say anything about how this apparatus is used to measure altitudes. In any case, he proceeds in principle exactly as Alfons does [see next page]. However, instead of aligning the sights to the Sun with the alidade, the *ṣafîḥa* and the astrolabe is rotated; in doing so the latter is freely suspended with the suspension apparatus until the gnomon throws a shadow on itself; this happens when the axis of the gnomon is aligned to the Sun. The altitude thus determined is read off at the divisions of the equator, at that spot where the tip of the *ṣafîḥa* with the gnomon rests. About the method for determining the altitude of stars which cannot be done with the gnomon, nothing is mentioned unfortunately, although al-Marrâkushî also speaks also of the determination of the altitudes of stars. — At the end al-Marrâkushî observes that in the same way as the equator it was also possible to use the ecliptic as 'the circle at which the altitude is measured', which is also the case with Alfons. Then the *ṣafîḥa* has to be attached at the ecliptic pole and the suspension apparatus mounted on the ecliptic in a suitable manner."[4]

Our model was made after the sketch by H. Seemann[5] and after his elucidation of the description by al-Marrākušī.

[4] H. Seemann, Th. Mittelberger, *Das kugelförmige Astrolab,* pp. 45–46 (reprint, op. cit., pp. 407–408).
[5] Ibid. p. 69 (reprint, p. 431).

4.
The spherical astrolabe

after the *Libros del saber de astronomía* (7th/13th c.)

Our model:
Brass, etched,
diameter: 17 cm.
(Inventory No. A 1.11)

The fourth treatise of the Alfonsine compendium devoted to astronomical instruments contains in 2 books and numerous sub-chapters a detailed description of the spherical astrolabe.[1] The treatise, like the other parts of the compendium, is said to have been written at the behest of King Alfons X (d. 1284) by a certain Rabiçag (Isak Ibn Sid) in the old Castilian language. Leaving aside the fact that it is not known whether this person was a Muslim, a Christian or a Jew, the question has also not yet been settled satisfactorily as to whether the work was translated from Arabic originals or was written independently in Castilian, on the basis of Arabic texts. It seems that Moritz Steinschneider with his explanation given in 1848 came closest to the facts of the case. According to his view, Arabic texts were first translated by Jews and then, on the basis of these translations, Christian scholars produced appropriate redactions and revisions.[2] This treatise which H. Seemann[3] examined and described in detail [**130**] enables us to get an idea of how far its content agrees with the extant Arabic treatises on the instrument. In many respects it shows indeed a close relationship with an-Nairīzī's text written some four hundred years earlier. However, in comparison to its predecessors known so far, the Castil-

[1] *Libros del saber de astronomía* del Rey D. Alfonso X de Castilla, copilados, anotados y comentados por D. Manuel Rico y Sinobas, vol. 2, Madrid 1863, pp. 113–222

[2] M. Steinschneider, *Alfons' X. «astronomischer Kongreß zu Toledo» und Isak Ibn Sid der Chasan*, in: Magazin für die Literatur des Auslandes (Berlin) 33/1848/226–227, 230–231 (reprint in: Islamic Mathematics and Astronomy, vol. 98, Frankfurt 1998, pp. 1–4); Alfred Wegener, *Die astronomischen Werke Alfons X.*, in: Bibliotheca mathematica (Leipig) 3. F., 6/1905/129–185, esp. p. 135 (reprint in: Islamic Mathematics and Astronomy, vol. 98, pp. 57–113, esp. p. 63).

[3] *Das kugelförmige Astrolab,* p. 7ff. (reprint, op. cit., pp. 369 ff.)

A: zodiac,
B: altitude quadrant,
C: shadow square,
D: calendar,
E: equator,
F: connecting pièces,
G: alidade,
H: sights,
R: suspension ring used while measuring altitudes.

Illustration from H. Seemann, Th. Mittelberger, *Das kugelförmige Astrolab,* p. 68 (reprint p. 430).

ian tract is substantially more detailed and more lucid in presentation. In my opinion we would, however, make a mistake if we wanted to understand this improvement as the result of an advance made by the Castilian redactors themselves. I am rather inclined to trace back the Castilian form to a younger Arabic version which, for its part, was already more elaborate. At the same time we should also take into account that one of the extant historical specimens of the spherical astrolabe (below, p. 131) dates from 1480 and turns out to be more advanced than all earlier literary descriptions as far as they are known to us. The testimony given by Alfonso X from the preface to the first book on the spherical astrolabe, "that he, since he had not found any book dealing with the manufacture of the spherical astrolabe, had given an order to the famous Isaak Ibn Sid to write such a work," [4] is more than doubtful. It is difficult to imagine that just on the basis of a specimen of the instrument type that may have reached Spain, a description of this nature should have been possible, leaving aside the fact that the entire text betrays its dependence on Arabic sources.

Our model was made after the drawing by H. Seemann[5] and after the description in the *Libros del saber de astronomía*.

[4] *Das kugelförmige Astrolab,* p. 7 (reprint, op. cit., p. 369).

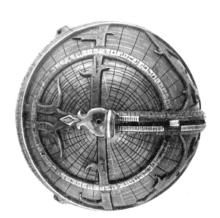
[5] Ibid., p. 68 (reprint, p. 430).

Spherical Astrolabe

of Arabic-Islamic provenience

(made 885/1480)

Our model:
Brass, etched,
diameter: 17 cm.
(Inventory No. A 1.12)

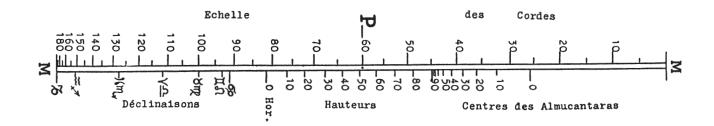
This spherical astrolabe found its way from the Arabic-Islamic area to Europe and was acquired by the Museum of the History of Science in Oxford at an auction in London in 1962.[1] It had been made in the year 885/1480 by a master called Mūsā.
The sphere is made of brass and has a diameter of 83 mm. It is enclosed by a rete (*ʿankabūt*, *šabaka*), to which a suspension ring is attached at the celestial North Pole. Compared to all other representations known to us, this specimen has two innovations, the first of which is of special significance. Namely, that the altitude measurements of both the Sun and the stars were done by means of a coaster which can be moved along the meridian up and down in the recess of a quadrant attached to the spider. A sight added to the coaster enabled the astronomer to sight the desired celestial body over the lower edge of the hole in the suspension ring. According to the photographs of the Oxford specimen at my disposal, this sight seems to be missing there. It probably had the form of a thin rod with a flat head with a small hole in the middle. For observation the sight was inserted into the coaster; at other times it was probably left hanging on a string from the coaster. I imagine its form to be such that a second sight with a sufficiently small hole could have been inserted into the opening of the pole's axis [**132**] because the slit at the suspension ring is too wide for accurate sighting.
The second innovation consists in a connecting mechanism between the spider and the sphere. That is to say, the spider can be moved in the vertical or horizontal direction for the purpose of observation without it losing contact with the convex surface of the sphere. This is assured by three brass arcs

[1] Francis Maddison, *A 15th Century Islamic Spherical Astrolabe*, in: Physis (Florence) 4/1962/101–109; see also *Astronomical Instruments in Medieval Spain*, Santa Cruz de la Palma 1985, p. 71.

On the left:
photographs
of the original
(from: Physis,
4/1962/101–109),
below:
our model (with
added alidade).

(which for their part are derived from a hemisphere with the same diameter as the spider), which, starting from the lower rim of the spider, enclose the lower part of the sphere.
The four photographs published by Maddison (above) convey a complete idea of the spherical astrolabe in Oxford.

A
Spherical Astrolabe
from the year 1070/1660

Our model:
Brass, etched.
Diameter: 8 cm.
Can be set to
different positions.
Stand, height: 11, 5 cm.
(Inventory No. A 1.13)

The second extant spherical astrolabe, according to our knowledge, is in the possession of the Museum for Islamic Art in Cairo. It dates from the year 1070/1660 and was made for a certain Ḍiyāʾaddīn Muḥammad b. al-ʿImād.

With this type of spherical astrolabe the essential information of the rete was transferred to the globe itself. The meridian ring carries several holes, made diametrically opposite, which make it possible by means of the axis to adjust the globe to corresponding circles of latitudes. The globe can also be used without its stand. It has a diameter of 8 cm.

The Linear Astrolabe
(*asṭurlāb ḫaṭṭī*)

The linear astrolabe, also called “aṭ-Ṭūsī’s staff” (*ʿaṣā aṭ-Ṭūsī*) is an invention of Šarafaddīn al-Muẓaffar b. Muḥammad b. al-Muẓaffar aṭ-Ṭūsī (d. after 606/1209)[1], who is considered in the history of mathematics to be a pioneer in the solution of numerical equations of any order.[2] A description of the instrument is preserved in the *Ǧāmiʿ al-mabādiʾ wa-l-ġāyāt* of Abu l-Ḥasan al-Marrākušī.[3] Louis-Amélie Sédillot[4] was the first to point this out in 1844. However, he thought that the inventor aṭ-Ṭūsī meant Naṣīraddīn aṭ-Ṭūsī.[5] In 1895 Baron Carra de Vaux examined the text in question and published it with a French translation.[6] About half a century after Carra de Vaux, Henri Michel[7] dealt with the same topic. He helped us to understand how this instrument, which had remained unknown for a long time, was to be used, and we are indebted to his preliminary work for being able to reconstruct it. The linear astrolabe consists of a staff upon which the projection of the planispheric astrolabe is transferred. Michel offers the following diagram:

Our model:
Wood, paper, strings with brass-weights.
Length: 46 cm.
(Inventory No. A 1.14)

Echelle des Cordes
Déclinaisons
Hauteurs
Centres des Almucantaras

[1] v. C. Brockelmann, *Geschichte der arabischen Litteratur*, vol. 1, p. 472, Suppl., vol. 1, pp. 858–859.
[2] v. Roshdi Rashed, *Résolution des équations numériques et algèbre : Šaraf-al-Din al-Ṭūsī, Viète*, in: Archive for History of Exact Sciences (Berlin etc.) 12/1974/244–290; idem, *Sharaf al-Dīn al-Ṭūsī : Œuvres mathématiques. Algèbre et géométrie au XIIe siècle*, 2 vols, Paris 1986; F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 5, p. 399.
[3] v. facsimile edition, Frankfurt 1984, vol. 2, pp. 99–109.
[4] *Mémoire sur les instruments astronomiques des Arabes*, pp. 27, 36, 191 (reprint, op. cit., pp. 73, 82, 237).
[5] v. B. Carra de Vaux, *L’astrolabe linéaire ou bâton d’et-Tousi*, in: Journal Asiatique (Paris), série 9, 5/1895/464–516, esp. p. 465 (reprint in: Islamic Mathematics and Astronomy, vol. 87, pp. 181–233, esp. p. 182).
[6] Ibid.
[7] *L’astrolabe linéaire d’al-Tûsi*, in: Ciel et Terre (Bruxelles) 59/1943/101–107 (reprint in: Islamic Mathematics and Astronomy, vol. 94, pp. 331–337).

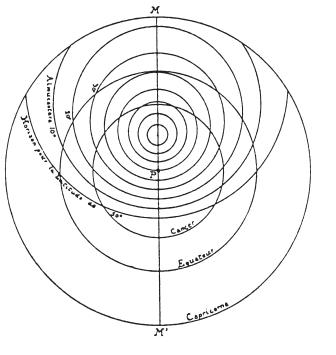
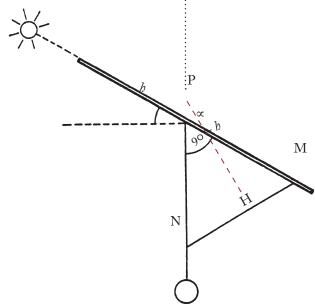
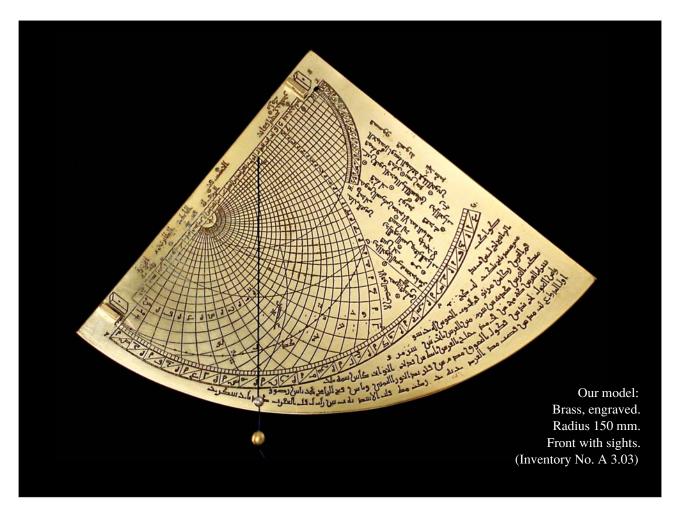



Fig. after H. Michel, modified.

From his description we learn the following details: The section MM' represents the intersection of the meridian circle with the horizontal plane on the disc of the common astrolabe. The distances of the curves from 0° to 180° of the circle with the radius MP are transferred to the staff. As an example the latitude of Brussels (50°50') was chosen.
Between starting point M and pole P we see on the right hand side of the scale the positions of the successive centres of the muqantarates (parallel circles) from 0° (horizontal plane) to 90° (zenith). After these, we see the intersections of the meridian with the altitude circles from 90° to the horizontal plane. Then follow, provided with the signs of the zodiac, the intersections of the meridian with the declination circles at the entrance of the star to be observed into each of the signs. To the left of the scale there is a graduation which indicates between starting point M at 0° and end point M' at 180°, lengths of the arc each of 5° for the circle with the radius MP. Depending on the desired degree of precision and depending on the length of the staff, it is possible to subdivide the scales further. For using the instrument at night, it was also possible to add to the circles of the declination of the Sun some circles of the declination of the major fixed stars. The scales are transferred to a suitable staff and three strings are attached to it.

Michel[8] explains the use of the instrument with the example of the determination of the Sun's altitude: At pole P a string with a lead weight is attached. The point N at a distance PN = PM is marked through a knot in the string. A second string is attached at the starting point M. Now the Sun is sighted along the length of the staff. In this position the second string is stretched from M to N and on it the intersection with N is marked. The length MN is measured with the scale; half of the result is divided by the known length PN = PM and the angle $\alpha = \frac{90-h}{2}$, is obtained; from this follows $h = 90-2\alpha$. The procedure of sighting sights could be done by means of a hole bored through the staff or with two sights set up on the staff, or with the help of notches on the upper part of the two knobs at the ends of the staff.

[8] *L'astrolabe linéaire d'al-Tûsi,* p. 106 (reprint, op. cit., p.336).

Our model:
Brass, engraved.
Radius 150 mm.
Front with sights.
(Inventory No. A 3.03)

Sine Quadrant

Based on an original of the sine quadrant (*ar-rubʿ al-muǧaiyab*) made by Muḥammad b. Aḥmad al-Mizzī in 734/1334 and preserved in St. Petersburg.

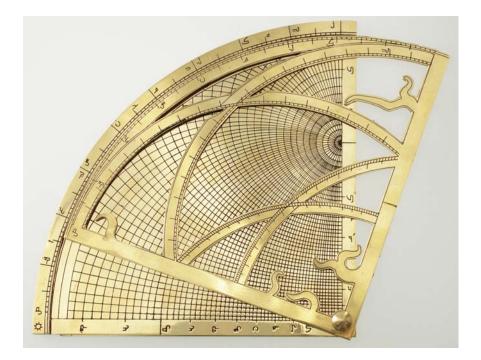
B. Dorn, *Drei in der Kaiserlichen Öffentlichen Bibliothek zu St. Petersburg befindliche astronomische Instrumente mit arabischen Inschriften*, St. Petersburg 1865 (= Mémoires de l'Académie impériale des sciences de St. Pétersbourg, VII[e] série, tome IX, no.1), pp. 16–26, 151–152 (reprint in: Islamic Mathematics and Astronomy, vol. 85, Frankfurt 1998, pp. 362–372, 497–498).

Sine Quadrant

Our model:
Brass, etched.
Radius: 135 mm.
(Inventory no. A 3.04)

Based on an original which was in Damascus until shortly before 1859, when it was acquired by the Arabist Alois Sprenger for the London librarian William Morley. The quadrant was made in 735/1335 by a certain ʿAlī b. aš-Šihāb and was engraved by an engraver called Muḥammad b. al-Ġuzūlī.

W. Morley, *Description of an Arabic Quadrant*, in: Journal of the Royal Asiatic Society of Great Britain and Ireland (London) 17/1860/322–330 (reprint in: Islamic Mathematics and Astronomy, vol. 85, Frankfurt 1998, pp. 322–336); cf. P. Schmalzl, *Zur Geschichte des Quadranten bei den Arabern*, Munich 1929, pp. 37–38 (reprint in: Islamic Mathematics and Astronomy, vol. 90, pp. 189–331, esp. pp. 225–226).

A ‹sexagesimal›

Sine Quadrant

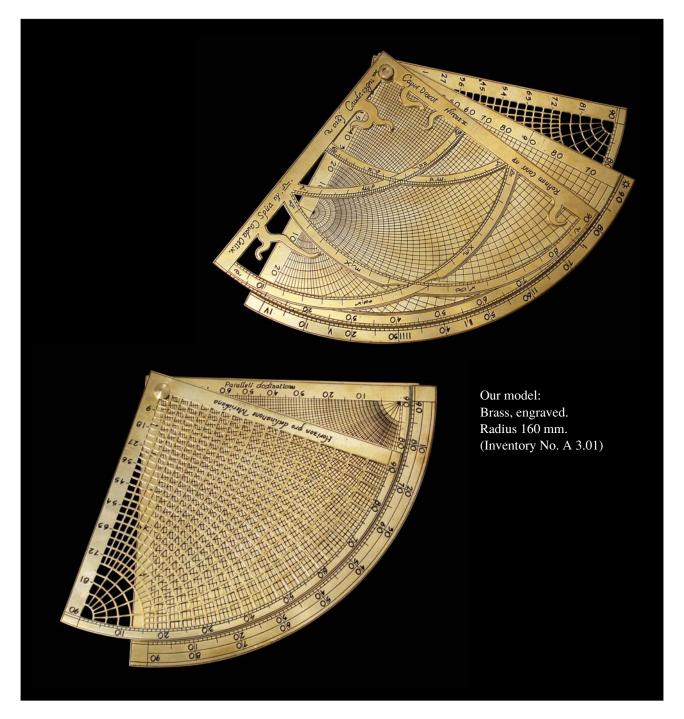
from the Maġrib

Our model:
Brass, engraved.
Radius: 125 mm.
(Inventory No. A 3.09)

The quadrant in the possession of our institute originates from the Maġrib and was presumably made in the 10th/16th or 11th/17th century. Its back is empty. It is divided into 60 equal parts, hence its name; the arc of altitude is divided into 90 degrees.

Besides the two systems of the *mabsūṭ* and the *mankūs* lines, it has two semicircular arcs (one above the sine line and the other above the cosine line) for converting the chord lengths into sine values, and a curve for determining the time of afternoon prayer (*ʿaṣr*). One of the two sights is missing.

Šakkāzīya

with Double Quadrant

Our model:
Brass, engraved.
Radius: 167mm.
(Inventory No. A 3.07)

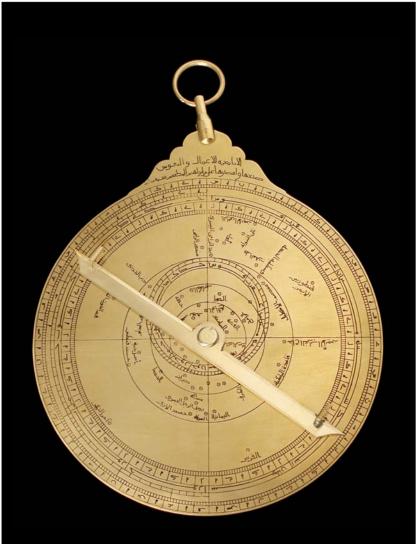
The Šakkāzīya with a double quadrant (*rubʿ aš-šakkāzīya*) was developed by Ǧamāladdīn ʿAbdallāh b. Ḫalīl al-Māridīnī (d. 809/1406) on the basis of az-Zarqālī's universal disc (above, p. 116). It was devised so that computations in spherical astronomy could be done with this instrument. The instrument itself is not extant, but a book by al-Māridīnī exists with a description and directions for its use. Besides this description, which is not detailed enough and presupposes knowledge we lack now, we have made use of an extant European imitation (see the following page) for our replica. The spider has the form of a quarter circle with pointers for seven fixed stars. Beneath this are a massive plate and a net-like one, both containing the Zarqālī-projection.

v. David King, *An Analog Computer for Solving Problems of Spherical Astronomy: The Shakkāzīya Quadrant of Jamāl al-Dīn al-Māridīnī*, in: Archives internationales d'histoire des sciences (Wiesbaden) 24/1974/219-241.

Our model:
Brass, engraved.
Radius 160 mm.
(Inventory No. A 3.01)

Double Quadrant

Based on an extant European original that was obviously made in the 9th/15th century in imitation of the instrument by al-Māridīnī (see the previous page) or of another Arabic prototype. The other characteristics of the device correspond to those of the preceding Šakkāzīya quadrant with the difference that the captions are in Latin here. The Šakkāzīya quadrant is also known as a meteoroscope.

(Original in the Adler Planetarium, Chicago)

Meteoroscope
by Peter Apian

Our model:
Brass, engraved.
Radius 150 mm.
A sine quadrant is located on the back, made with great precision, above it a movable ruler.
Replica by Martin Brunold (Abtwil, Switzerland)
(Inventory No. A 3.02)

Made after the description by Peter Apian (1501-1552) in his Astronomicum Caesareum. It is now fairly established that Apian plagiarised the instrument of his predecessor Johannes Werner, whose Arabic prototype went back to az-Zarqālī's universal disc.

J.D. North, *Werner, Apian, Blagrave and the Meteoroscope*, in: The British Journal for the History of Science (London) 3/1966–67/57–65.

Our model:
Brass, engraved.
Radius 18 cm.
(Inventory No. A 3.10)

‹*dastūr*› Quadrant

The Dastūr Quadrant (Arabic *dāʾirat ad-dastūr* or *ad-dustūr*) was made after an original with a diameter of 182 mm in the Museum for Islamic Art in Cairo. On the back it carries the projection of the horizontal plane of a place whose latitude could lie between 30° and 33°. Instead of the parallel and vertical circles, we see the basic circles and the positions of some select stars together with the chords. The instrument was made by ʿAlī b. Ibrāhīm al-Muṭaʿʿim in the year 734/1334. The two alidades, missing in the original, were added by us.

Quadrant Disc

Our model:
Brass, engraved.
Radius 25 cm.
(Inventory No. A 3.11)

It is a combination of quadrants in a form so far unknown to me, which apparently originates from the Maġrib. The instrument is in the possession of our Institute's museum. Its circular disc of brass has a diameter of 250 mm and a thickness of 0.8 mm. On the upper rim at the back two quadrants are engraved, each of which is divided into 90°. Altitude measurements can be done with an alidade.
On the front there is a sexagesimal quadrant with *mabsūṭ* and *mankūs* lines and two semicircular lines, one above the sine and the other above the cosine line for converting chord lengths into sine values.
Given the whole configuration, I wonder whether this is perhaps not an incomplete piece.

Quadrant

Replica of a European quadrant from the 18th century.

Our model:
Brass, engraved.
Radius 120 mm.
(Inventory No. A 3.05)

OTHER OBSERVATIONAL AND MEASURING INSTRUMENTS

Indian Circle

(*ad-dāʾira al-hindīya*)

Our model:
Brass, engraved.
Diameter: 250 mm.
Height of the gnomon: 63 mm.
(Inventory no. A 4.25)

A gnomon has been fixed at the centre of the circle. The direction of the meridian is determined by the straight line passing through the middle of the line between the point of entry of the shadow into the circle and the point of its exit and through the centre of the circle. The instrument was known to the Greeks and in other cultures.

L.A. Sédillot, *Mémoire,* pp. 98 ff.; E. Wiedemann, *Über den indischen Kreis*, in: Mitteilungen zur Geschichte der Medizin und der Naturwissenschaften (Leipzig, Hamburg) 11/1912/252–255 (reprint in: Islamic Mathematics and Astronomy, vol. 34, Frankfurt 1998, pp. 56–59).

Instrument
For Determining the Meridian

In the first half of the 5th/11th century the two astronomers Abu r-Raiḥān Muḥammad b. Aḥmad al-Bīrūnī and al-Ḥasan b. al-Ḥasan Ibn al-Haiṯam had, for the first time, clearly understood that the traditional graphical procedure for determining the direction of the meridian with the help of the shadow and by means of the "Indian Circle" was defective. While al-Bīrūnī thought of some new procedures, Ibn al-Haiṯam arrived at the method of determining the direction of the meridian through the corresponding altitudes of the fixed stars. From remarks in his treatise on his procedure and on the "instrument for determining the meridian" developed for this purpose (*āla li-stiḫrāǧ ḫaṭṭ niṣf an-nahār*), it appears that this problem preoccupied Ibn al-Haiṯam for a long time and that he is indeed the inventor of this instrument. No doubt the use of the angular distances of a fixed star before and after its culmination for determining the elevation of the pole was already known before Ibn al-Haiṯam, but he seems to have been the first to have developed the operation with corresponding altitudes of fixed stars to a clearly defined, experimentally proven astronomical procedure. In the Occident the procedure appears for the first time in Regiomontanus' work in the second half of the 15th century (v. R. Wolf, *Handbuch der Astronomie* I, 390-391). In the procedure with our device, half the sum of two horizontal angles is determined by observing a fixed star after dusk up to the culmination and from the culmination until shortly before dawn. What is decisive in this procedure is that the pointer below, when the connecting column is turned, produces converging angular distances, so that half the sum of the traversed angles on the lower horizontal semicircle determines the direction of the meridian.

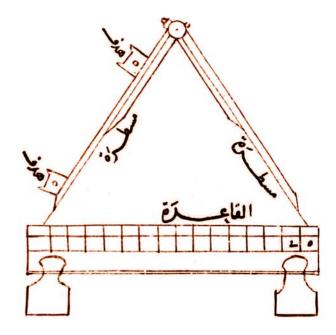
Our model: Brass, gilded. Hard wood. Height: 1 m. (Inventory No. A 4.21)

F. Sezgin, *Ṭarīqat Ibn al-Haiṯam fī maʿrifat ḫaṭṭ niṣf an-nahār*, in: Zeitschrift für Geschichte der arabisch–islamischen Wissenschaften (Frankfurt) 3/1986/arab. 7–43.

‹The Instrument with the triangle›

Our reconstruction:
Brass, etched.
Hard wood. Plumb.
(Inventory No. A 4.24)

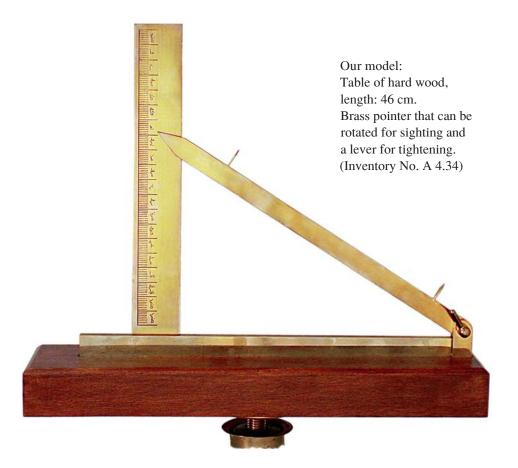
The astronomer and physicist ʿAbdarraḥmān al-Ḫāzinī (1st half of the 6th/12th c.), in his *Ittiḥād al-ālāt ar-raṣadīya*,[1] describes among other astronomical instruments the "instrument with the triangle" (*al-āla ḏāt al-muṯallaṯ*) which is used to solve the following two tasks:
1.Determining the altitude of celestial bodies, like a common quadrant.
2.Determining the angle of vision in which an object appears to us.
Al-Ḫāzinī reports that al-Bīrūnī briefly mentioned this instrument in his *Taḥdīd nihāyāt al-amākin*.[2] Al-Ḫāzinī deals with all the instruments which he introduces in three sections: 1. manufacture of the instrument, 2. its use, 3. reasons for the correctness of what was said. On the basis of the first chapter and part of the second chapter, which are preserved in an anonymous compilation on astronomical instruments in a Berlin manuscript (Sprenger 1877, Ahlwardt 5857, 124a f.), Josef Frank made known the instrument in 1921.[3] Partly translating the author's account, Frank describes its features thus: "In a right-angled triangle of wood or other material, around the centre of the hypotenuse, a semi-circle is drawn which touches the smaller sides of the triangle and is divided into 180 degrees. At the ends of the hypotenuse are mounted two vertical pieces which serve as the sights. By means of a hinge attached at the apex of the right angle, the triangle is attached to a base, a rectangular slab. The front side of this base is graduated; each part is equal to the sixtieth part of the height of the triangle. The instrument is basically a double quadrant and serves primarily to measure the magnitude of an angle. But in some respects it achieves more than the double quadrant, which can directly measure only that angle which a visual ray forms with the horizontal line. Whereas with the triangle instrument it is also possible to represent a vertical angle if the horizontal also lies within the area of the angle. The divisions on the base make it possible to determine the sine of any angle by means of the plumb line attached to the centre of the circle."

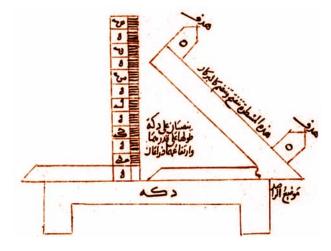
Illustration from MS Istanbul, Bibl. univ., A.Y. 314.

[1] The manuscript used is in the University Library in Istanbul, A.Y. 314 (54b–82b, 9th c. H., v. F. Sezgin, *Geschichte des arabischen Schrifttums,* vol. 6, p. 92). With the complete manuscript the text was published in facsimile as *Maǧmūʿat rasāʾil ʿarabīya fī ʿilm al-falak wa-r-riyāḍīyāt*, Frankfurt: Institut für Geschichte der Arabisch-Islamischen Wissenschaften, 2002, pp. 114–166.
[2] al-Ḫāzinī probably means the statement on p. 221 of the edition available to us (Cairo 1962), which is in fact very brief and only makes mention of the second task.
[3] *Über zwei astronomische arabische Instrumente*, in: Zeitschrift für Instrumentenkunde (Berlin), 41/1921/193–200, esp. pp. 199–200 (reprint in: Islamic Mathematics and Astronomy, vol. 88, Frankfurt 1998, pp. 69-70).

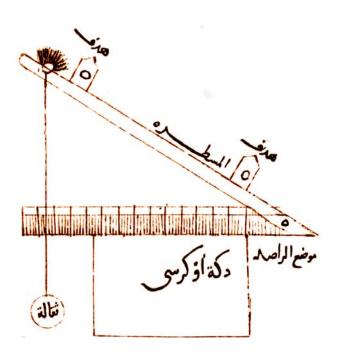
Three instruments for Measuring Altitudes

In his *Kašf ʿawār al-munaǧǧimīn wa-ġalaṭihim fī akṯar al-aʿmāl wa-l-aḥkām*, known so far in two manuscripts, the universal scholar Abū Naṣr as-Samauʾal b. Yaḥyā al-Maġribī [1] (d. ca. 570/1175) describes three instruments used by his predecessors for measuring altitudes, and he takes pains to point out their possible shortcomings.

From MS Oxford, Hunt. 539.

1)

With the first of the devices, one operates with an angle meter is operated that consists of two arms of equal length, one of which is attached to the beginning of a ruler, set up horizontally, while the other one moves along the ruler on a movable rail on the table that carries the instrument. The altitude established by the two sights on the first arm is computed by means of the ratio between half of the distance between the tips of the two arms at the time of observation and the length of the arms. The ratio gives the cosine of the angle of altitude.

Our model:
Table of hard wood,
length: 66 cm.
Scale mounted on the side, engraved Arabic letters with numerical values.
(Inventory No. A 4.33)

[1] v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 6, pp. 65.

Our model:
Table of hard wood,
length: 46 cm.
Brass pointer that can be rotated for sighting and a lever for tightening.
(Inventory No. A 4.34)

2)
Two arms are used with the second instrument for measuring altitudes, one of which is equipped with a pointed end and two sights and is adjustable in its height at the hinge of the apex. The second arm is provided with a rail in which a movable ruler stands at an angle of 90°. On the ruler the angle of altitude is measured with the pointed end of the first arm by sighting. The ratio of the distance between the point on the ruler where the arm rests and its lower end to the known length of the arm results in the sine of the ascertained altitude.

From MS Oxford, Hunt. 539.

Our model:
Table of hard wood,
length: 63.5 cm.
A scale is mounted on
one side of the table with
engraved Arabic letters
with numerical values.
(Inventory No. A 4.35)

From MS Oxford, Hunt. 539.

3)
In the third instrument for measuring altitudes, two arms of equal length are joined to each other by a hinge, like the arms in a pair of dividers. One of the arms is firmly set in the horizontal plane and carries a measuring scale, while the other is equipped with sights. The height of the second arm can be adjusted; it carries a plumb line at its end. The ratio of the distance from the beginning of the horizontal ruler up to the point touched by the plumb line to the length of the movable arm yields the cosine of the angle of altitude of the object sighted.

The universel instrument

(*al-āla aš-šāmila*)

Our model:
Brass, etched.
Diameter = 42 cm,
inner radius = 17 cm.
(Inventory No. A 1.06)

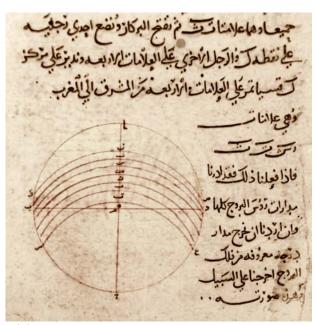
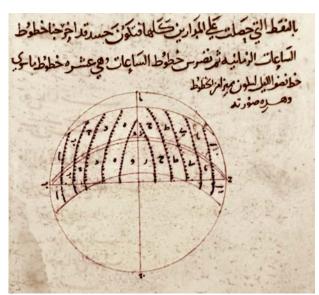
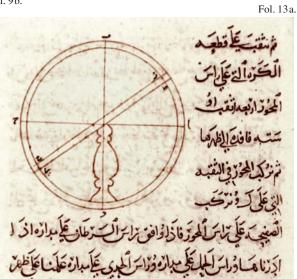
The inventor of this instrument was the famous mathematician and astronomer Ḥāmid b. al-Ḫiḍr al-Ḫuǧandī[1] (2nd half of th 4th/10th c.). Before the discovery of the book's manuscript[2] in which al-Ḫuǧandī described the instrument, quotations from it were known from al-Marrākušī[3] (2nd half of the 7th/13th c.). In 1921 Josef Frank[4] was able to describe the instrument almost realistically based on extracts from al-Ḫuǧandī's book in a Berlin manuscript:[5]

"Basically the instrument consists of a hollow hemisphere and a disc of the size of one of its great circles. The circular rim of the hemisphere, divided into degrees, represents the horizon. On its inner surface the parallel and vertical circles of the horizon are drawn. This means the hemisphere is to be understood as that part of the celestial sphere which is under the horizon with the horizontal system of coordinates. The disc is divided into 360 degrees and rotates around the centre of the hemisphere like the plane of the ecliptic; thus the revolution of the zodiac is represented. To adjust the disc for each geographical latitude, the position of the axis attached to it can be moved through a slit in the hemisphere. For measurements on the celestial equator, a semicircle [on the inner surface of the hemisphere] is connected to the disc in its given position, the semicircle representing one half of the celestial equator. An alidade that can be rotated around the centre of the disc permits measurements of many different angles, either in the plane of the ecliptic for the determination of longitudes, or in the plane of the celestial equator to find right ascensions. For this, the axis is moved to a suitable position. When the disc is positioned vertically to the horizon, the altitude can be measured. However, generally with these measurements, the sight which is in the inside of the sphere makes the alignment of a star difficult. This drawback can be avoided if the disc is separated from the axis and is suspended it vertically. A hole on the rim of the disc at the 90th degree division serves perhaps just this purpose. Altitudes are measured with the disc in the same manner as with the back of the astrolabe. From the system of horizontal coordinates, the altitude and azimuth of the point of the ecliptic situated opposite the Sun can be read off, from which these coordinates for the Sun itself are obtained. With their help it is possible to represent on the disc the zodiac in its position in the celestial sphere for that moment. The circle of the equator allows the measurement of time …"

[1] v. F. Sezgin, *Geschichte des arabischen Schrifttums,* vol. 5, pp. 307-308; vol. 6, pp. 220–222.
[2] Ibid., vol. 6, p. 221.
[3] *Ǧāmiʿ al-mabādiʾ wa-l-ġāyāt*, facsimile edition, Frankfurt 1984, pp. 14–19; L.-A. Sédillot, *Mémoire sur les instruments astronomiques des Arabes*, pp. 148–149 (reprint, op. cit., pp. 194–195).
[4] *Über zwei astronomische arabische Instrumente*, in: Zeitschrift für Instrumentenkunde (Berlin) 41/1921/193–200 (reprint in: Islamic Mathematics and Astronomy, vol. 88, pp. 63-70).
[5] *Muḫtaṣar fī ṣanʿat baʿḍ al-ālāt ar-raṣadīya wa-l-ʿamal bihā*, MS Ahlwardt 5857 (Sprenger 1877).

Axis of the disc, bevelled at the top and with a peg below, which moves in the rail; from MS Bursa, Haraççıoğlu 1217, fol. 12a. .

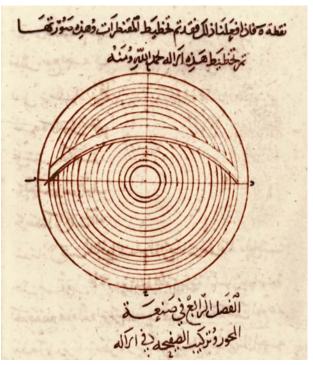
"Therefore it is possible to consider the shâmila as a combination of the quadrant or of the rear of the astrolabe with the celestial globe. It already functions as a quadrant because of the features just mentioned; in contrast to the quadrant, it has the advantage that it facilitates the perception of space more clearly. While the châmila only makes it possible to directly perform the observations related to the Sun, similar observations can also be carried out in connection with fixed stars with the astrolabe and the celestial globe; because the positions of these stars, or at least of the most important of them, are marked on these instruments. Furthermore, the celestial globe makes it possible to represent the motion of the entire celestial sphere, while the shâmila only represents that of the zodiac and of the equator. Nevertheless, the factor of spatial perception in the châmila cannot be ignored. In other words, while with the celestial globe we have to imagine ourselves to be situated outside the celestial sphere, with the shâmila we see the situation as in factual reality. From the centre of the sphere we observe how, e.g. the zodiac moves past the muqantaras and the azimuthal circles, which we see on the inner surface of the celestial globe…."[6].

For the construction of our model, we relied on the work of J. Frank and on al-Ḫuǧandī's complete description from the manuscript Bursa, Haraççıoğlu No. 1217, which was not yet known to Frank. In addition, we constructed a 90 degree scale, which consists of an arc of a quarter circle, whose radius corresponds to the inner radius of the hemisphere. The scale is attached to the axis in such a way that it rotates with the turning of the axis and, while rotating touches the inner side of the hemisphere.

The scale can be seen in the photographs in the top right-hand corner. The scale enables us to read off the measurements in the inner side of the sphere by individual degrees. A corresponding subdivision of the celestial meridians and the parallel circles on the inner surface of the sphere would be technically difficult even now.

[6] J. Frank, *Über zwei astronomische arabische Instrumente*, p. 194–195 (reprint, op. cit., p. 64–65).

Fol. 9a.

Fol. 10b.

Fol. 9b.

Fol. 13a.

Fol. 11b.

Construction drawings from the MS Bursa, Haraççıoğlu No. 1217

The
Torquetum

Our model:
Brass, etched.
Diameter 30 cm.
Height 75 cm.
The device can be set around three axes.
The latitude can be adjusted.
(Inventory No. A 4.20)

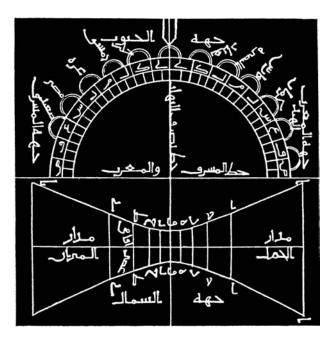
The torquetum was developed by the Andalusian astronomer Ǧābir b. Aflaḥ in the 6th/12th c. and enjoyed wide distribution from the 15th century in Europe, particularly among German astronomers. The instrument is described in Ǧābir b. Aflaḥ's *Iṣlāḥ al-Maǧisṭī*.[1] It represents the celestial planes of horizon, equator and ecliptic, which can be rotated one above the other, and serves the following tasks:
1. Determination of the size of the arc of the meridian between the two tropics (*miqdār al-qaus allatī bain al-munqalabain*).
2. Determination of the altitude of the Moon (*nihāyat mail al-qamar min falak al-burūǧ*).
3. Determination of the two equinoxes (*waqt kull wāḥid min al-iʿtidālain*).
4. Determination of the positions of stars (*mauḍiʿ kaukab min al-kawākib min falak al-burʿǧ fi ṭ-ṭūl wa-l-ʿarḍ*).
The instrument was already known in Europe in the 13th century.

Our model with Arabic script and Arabic numerals was constructed on the basis of specimens extant in Europe.

[1] v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 6, p. 93.

L. Thorndike, *Franco de Polonia and the Turquet,* in: Isis (Cambridge, MA) 36/1945/6–7; E. Zinner, *Deutsche und niederländische astronomische Instrumente des 11. bis 18. Jahrhunderts,* Munich 1956, pp. 177–183; E. Poulle, *Bernard de Verdun et le Turquet,* in: Isis 55/1964/200–208; Richard P. Lorch, *The Astronomical Instruments of Jābir ibn Aflaḥ and the Torquetum*, in: Centaurus (Copenhagen) 20/1976–77/11–34.

The
Torquetum Family

External view (astrolabe) of our model.

1. *Ṣandūq al-yawāqīt al-ǧāmiʿ li-aʿmāl al-mawāqīt*

(‹Casket of rubies for all types of time measurement›)

The "ruby-casket" was constructed by the famous astronomer ʿAlī b. Ibrāhīm Ibn aš-Šāṭir (d. ca. 777/1375) in 767/1366 for one of the Mameluk governors in Damascus. It contains two sundials, a polar one and an equatorial one. The latter serves to determine the hour angle according to the position of the Sun or of a star outside the zone of the equator. Today the instrument is with the Auqāf Library at Aleppo. It was made known for the first time in 1939-40 by Siegmund Reich and Gaston Wiet.[1] This enabled the authors of the *History of Technology*[2] of 1957 to give a brief description. Then, in

Rubbing of the lost inner disc, after S. Reich and G. Wiet.

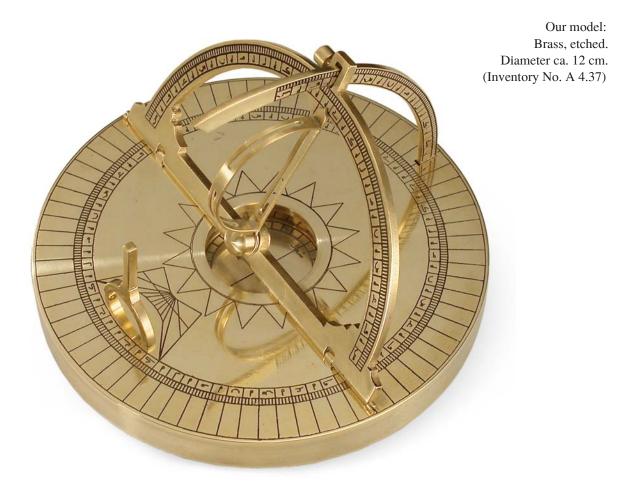
[1] *Un astrolabe syrien du XIV^{e} siècle*, in: Bulletin de l'Institut Français d'Archéologie Orientale (Cairo) 38/1939/195–202 (reprint in: Islamic Mathematics and Astronomy, vol. 95, pp. 4–11).
[2] Charles Singer, E.J. Holmyard, A.R. Hall, Trevor J. Williams (ed.), *A History of Technology*, vol. 3, Oxford 1957, p. 600 and figure 353.

Our model:
Brass, etched.
12 × 12 × 2, 5 cm.
Disc with gnomon adjustable
to different latitudes.
(Inventory No. A 4.36)

1976, it was [**156**] shown in the exhibition Science and Technology in London. Subsequently it was examined and described by Louis Janin and David A. King. In this study[3] the instrument is not only evaluated historically, but an anonymous incomplete treatise is also edited with it and translated into English, which the authors assume had been written by Ibn aš-Šāṭir to explain the instrument. However, the two scholars come to the conclusion that the anonymous text cannot provide the anticipated help in removing the difficulties connected with understanding the instrument; particularly because of its incompleteness, it creates as many problems as it solves.[4] I wonder if the reason for this might not lie with the identity of the author. Perhaps it was not Ibn aš-Šāṭir himself but another scholar who described the instrument with certain deviations. The difficulties mentioned arise mainly because some accessories of the instrument are missing. It is to be regretted that the two sights of the alidade are missing, one of which was still extant at the London exhibition. But more important, no doubt, is the loss of the movable disc with the diagram of the sundial of which we can now have an idea only from the rubbing by Reich and Wiet (see picture p. 155).
In our model we set up a gnomon at the intersection of the coordinates, the length of which corresponds to the distance between the centre point and the eight-hour line. On the lid we added two sights, for the length and height of which we relied on a photograph from the London exhibition.[5] On one of the inner surfaces of the casket we drilled six cavities at which the names and latitudes of six cities are engraved; while doing so, we started with the assumption that [**157**] a small post existed as a support for adjusting the desired latitude; the adjustment was probably done by inserting the post between the movable disc and the cavities made at appropriate

[3] *Ibn al-Shāṭir*'s *Ṣandūq al-Yawāqīt: An Astronomical ‹Compendium›*, in: Journal for the History of Arabic Science (Alep) 1/1977/187–256 (reprint in: D. A. King, *Islamic Astronomical Instruments*, London: Variorum, 1987, text no. XII).
[4] Ibid., pp. 188, 189.

[5] v. Ḥusain Naṣr, *al-ʿUlūm fī l-Islām. Dirāsa muṣauwara* (translated from the English), Tunis 1978, p. 89.

places in the wall on the side of the casket; thus the post allowed an inclination of the disc corresponding to the respective latitude. In more advanced successors of the device, a graduated quadrant (below, p. 158) served to adjust the apparatus for the local latitude. The meridional alignment of the portable casket was done, according to the descriptive text, by means of a compass (*ʿibra*). Probably a compass of suitable size was installed at the bottom of the device.
Presumably this is how the apparatus was used: After opening the upper lid by 180° and aligning the casket to the meridian, the southern edge of the lower movable plate is lifted up to the latitude of the place of observation.
After that, the increasing or decreasing length of the shadow is observed. The intersections of the shadow with the northern or southern time curve mark the passing of the local hours. Along the outer semicircle geographical places are recorded. They stand for the zones whose *qibla* direction can be ascertained according to the adjustment of the casket. The provinces and localities Ṣaʿīd (Upper Egypt), Miṣr (Cairo), Ġazza, Dimašq (Damascus), Ḥalab (Aleppo), Baghdad, al-Baṣra, Fāris (the Persis), Kirmān and al-Hind (Central India) are mentioned. When the casket is closed, the lid performs the tasks of an astrolabe.
The special importance of the instrument for the history of astronomy lies in the fact that it proves to be a new step in the course of development towards that instrument which came to be known as the torquetum in Europe (above, p. 154). In the following centuries this type, under the name *dāʾirat muʿaddil an-nahār*, caused the emergence of numerous successors with their own individual courses of development. This also applies to their European followers. The successors of the "ruby casket" in the Arabic-Islamic area presently known are: *Dāʾirat al-muʿaddil*, described by its maker ʿIzzaddīn ʿAbdalʿazīz b. Muḥammad al-Wafāʾī (d. 874/1469).[6] The Arabic description with Turkish and English translation was edited by Sevim Tekeli in 1960.[7] Muḥammad b. Abi l-Fatḥ aṣ-Ṣūfī (still alive 943/1536), who had already described the "ruby casket" under the title *al-ʿAmal bi-ṣandūq al-yawāqīt*,[8] also left behind the description of a device of great similarity to that of ʿIzzaddīn al-Wafāʾī. He called his work *al-Mufaṣṣal fi l-ʿamal bi-niṣf dāʾirat al-muʿaddil*.[9]

[6] v. C. Brockelmann, *Geschichte der arabischen Litteratur*, Suppl., vol. 2, p. 160.
[7] *Izzüddin b. Muhammed al-Vefai'nin ‹Ekvator halkası› adlı makalesi ve torquetum* (titre angl. *‹Equatorial Armilla› of ʿIz al-Din b. Muḥammad al-Wafai and Torquetum*), in: Ankara Üniversitesi Dil ve Tarih–Coğrafya Fakültesi Dergisi (Ankara) 18/1960/227-259.
[8] Edited by David King, *Ibn al-Shāṭir*'s *Ṣandūq al-Yawāqīt,* pp. 248–250.
[9] v. Sevim Tekeli, *Izzüddin b. Muhammed al-Vefai'nin ‹Ekvator halkası›,* pp. 227–228.

Our model:
Brass, etched.
Diameter ca. 12 cm.
(Inventory No. A 4.37)

2.

The description of a more advanced type of this instrument was discovered by William Brice, Colin Imber and Richard Lorch[10] in the treatise *Mirʾāt-i kāʾināt min ālāt-i irtifāʿ* of the well-known Ottoman navigator Sīdī ʿAlī Reʾīs (d. 970/1562).[11] They prepared the following diagram of the device described by Sīdī ʿAlī:

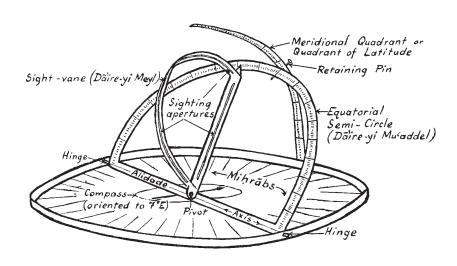
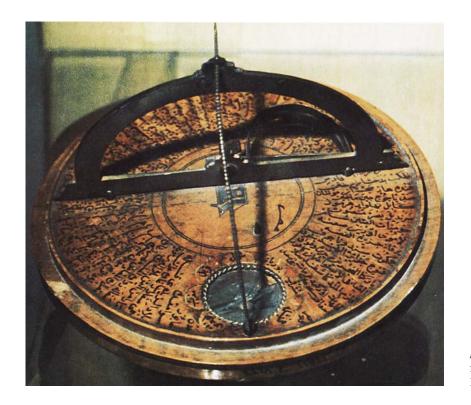



Fig. from Brice/Imber/Lorch,
The Dāʾire-yi Muʿaddel of Seydī ʿAlī Reʾīs, p. 5.

[10] *The Dāʾire-yi Muʿaddel of Seydī ʿAlī Reʾīs*, publié sous le titre: Seminar on Early Islamic Science. Monograph No. 1 (July 1976).
[11] v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 11, pp. 159–168, 265–268.

Dāʾirat al-muʿaddil from Damascus, National Museum, No. 11741[13].

What is most remarkable in this connection is that Sīdī ʿAlī points out the necessity of taking the magnetic deviation of 7° of the meridian circle passing through Istanbul into account, while using the built-in compass. An instrument largely resembling the one described by Sīdī ʿAlī is preserved in the National Museum in Damascus (No. 11741). Its semicircle bears the date 1050 (= 1640 A.D.) while, according to an inscription on the equatorial circle, it dates from the year 1104 (= 1693 A.D.). Therefore, it seems to have been assembled from two parts dating from two different times[12].

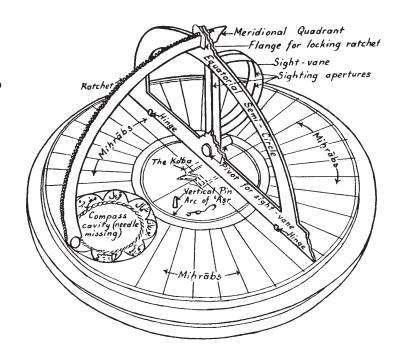
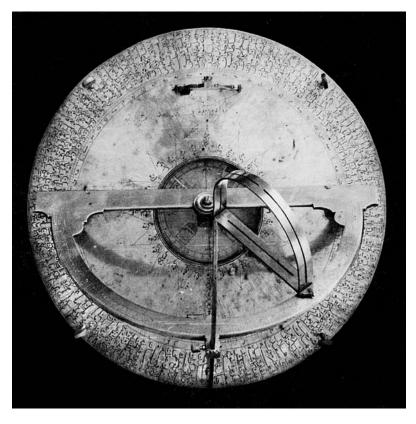
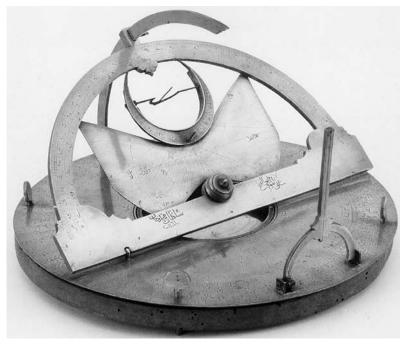



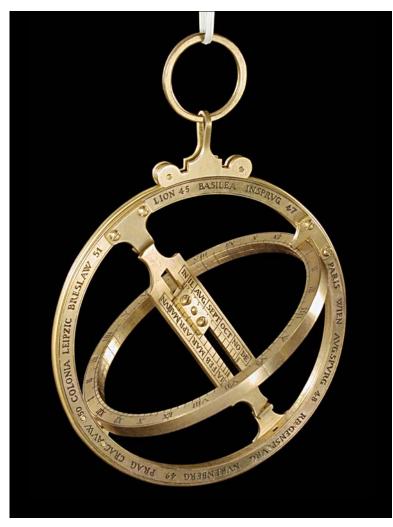
Diagram of the instrument from Damascus, National Museum, No. 11741[14].

[12] W. Brice, C. Imber, R. Lorch, *The Dāʾire-yi Muʿaddel of Seydī ʿAlī Reʾīs*, op. cit., p. 6.

[13] From Ḥusain Naṣr, *al-ʿUlūm fi l-Islām. Dirāsa muṣauwara*, op. cit., p. 45.

[14] From W. Brice, C. Imber, R. Lorch, *The Dāʾire-yi Muʿaddel of Seydī ʿAlī Reʾīs*, op. cit., p. 7.

On the further development of the instrument we may cite two more examples:

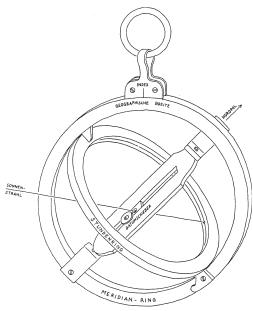
1) The specimen of the observatory of Kandilli in Istanbul[15].

Dāʾirat al-muʿaddil, from Kandilli[16].

2) Another type of equatorial clock (*muʿaddil an-nahār*) was made by the same instrument maker who made the device in Kandilli in the year 1061/1651[17] for Sultan Mehmed IV. The specimen which was in the possession of Christie's of London a few years ago is equipped with two additional sundials, but the sighting aperture is missing.

Muʿaddil an-nahār of 1061/1651[18].

[15] v. Muammer Dizer, *The Dāʾirat al-Muʿaddal in the Kandilli Observatory, and Some Remarks on the Earliest Recorded Islamic Values of the Magnetic Declination*, in: Journal for the History of Arabic Science (Alep) 1/1977/257–262; David A. King, *An Islamic Astronomical Instrument*, in: Journal for the History of Astronomy (Cambridge) 10/1979/51–53 (reprint in: idem, *Islamic Astronomical Instruments*, London: Variorum Reprints, 1987, nº XIII).

[16] From D.A. King, *An Islamic Astronomical Instrument*, op. cit., p. 52.

[17] The date was inadvertently engraved wrongly on the instrument. The year 1161 is written instead of 1061. The instrument in Kandilli, mentioned above, dates from 1066/1656, the maker of both instruments called himself ʿAlī al-Muwaqqit Abu l-Fatḥ, v. M. Dizer, *The Dāʾirat al-Muʿaddal in the Kandilli Observatory,* p. 258 and picture 2.

[18] From David A. King, *World-Maps for Finding the Direction and Distance to Mecca*, Leiden 1999, p. 302.

Equatorial Ring
Sun-Dial

Our model:
Brass.
Diameter: 100 mm.
Weight: ca. 0.25 kg.
(Inventory No. B 2.10)

Drawing by M. Brunold.

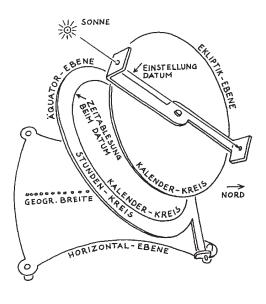
The instrument functions according to the principle that the latitude of the equatorial plane is aligned to the horizontal plane of the place of observation. Thus this European sundial is part of the tradition of the devices called *dā'irat mu'addil an-nahār* from the Arabic-Islamic world. This type seems to have been widespread in Europe in the 17th and 18th centuries. In the Amsterdam exhibition catalogue Time[19] of 1990, two such specimens are shown. One of them is in private possession, not closely specified, the other is in the museum of Utrecht University (No. A 34). Our model was constructed by Martin Brunold (Abtwil, Switzerland).

He gives the following instructions for using of the instrument:
1) Direct the index on the movable suspension ring to the geographical latitude.
2) Adjust the date slide.
3) Lift the hour ring up to the stop. Now it is at right angles to the meridian ring. The hour ring corresponds to the celestial equator.
4) Let the sundial hang freely from the suspension ring. The rotating axis of the date slide represents the Earth's axis…The instrument must be moved back and forth a little around the vertical axis until the Sun's ray passes through the hole in the date slide and falls upon the middle of the inner edge of the hour ring. There the true local time can be read off. The date slide can be turned to and fro and must be placed vertically in the sunlight.

[19] *Time*. Catalogue edited by A.J. Turner, Texts by H.F. Bienfait, E. Dekker, W. Dijkhuis, V. Icke, and A.J. Turner, The Hague 1990, p. 129, nº 256 and figure p. 139.

Size: 10 × 10 c.
Brass, engraved.
Inclination adjustable,
sights and calendar circle
can be rotated around the axis.
(Inventory No. B 2.11)

A Table Sundial

A demonstration model, constructed by Martin Brunold (Abtwil, Switzerland) on the basis of originals from the 17th century. In his instructions, he explains the procedure as follows: "The small table sundial is based on the principle of the torquetum … The three most important celestial planes, horizon, equator and ecliptic (the Sun's orbit) are arranged one upon the other, and can be rotated; they permit the representation of the celestial motions occurring at the respective place of observation. The bottom disc with its four feet corresponds to the horizontal plane. It is initially placed on a horizontal surface, approximately according to the points of the compass, with the hinge pointing to the north … Above the bottom disc follows the disc that represents the plane of the celestial equator; it can be lifted up. The tilting of this surface depends on the geographical latitude of the place of observation … The plane of the equator carries the hour circle above which rotates a date disc. When the instrument is aligned to the Sun, the true local time with the correct date can be read off."

Our model:
Brass, etched.
Size: 10 × 10 cm.
Weight: ca. 250 gr.
Inclination adjustable.
Sights and calendar circle.
(Inventory No. B 2.14)

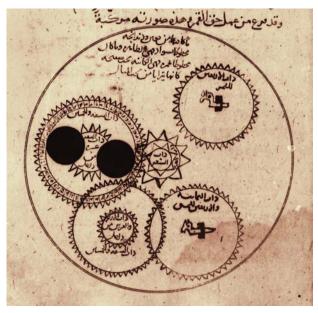
Another
Table Sundial

A clock based on the same principle as the previous one. It was also constructed by Martin Brunold (Abtwil, Switzerland).

SONNE
EKLIPTIK-EBENE
ÄQUATOR-EBENE
EINSTELLUNG DATUM
ZEITABLESUNG BEIM DATUM
KALENDER-KREIS
STUNDEN-KREIS
KALENDER-KREIS
GEOGR. BREITE
NORD
HORIZONTAL-EBENE

Drawing by M. Brunold.

Mechanical-Astronomical Calendar

by al-Bīrūnī

Our model:
diameter: 22 cm.
Brass, partly engraved.
Front disc of glass.
(Inventory No. B 3.05)

In his *Istīʿāb*,[1] a book on the manufacture of astrolabes, the universal scholar Muḥammad b. Aḥmad al-Bīrūnī (d. 440/1048) describes a mechanical-astronomical calendar called *ḥuqq al-qamar* ("moon-box"). He wants to use it "to determine the waxing and waning of the Moon, that part of the month which has elapsed and the approximate position of the two luminaries (namely the Sun and the Moon)." Eilhard Wiedemann [2] deserves credit for having been the first to recognise the importance of the instrument and to have made it known through a detailed description.

Sonne VIII a b VII I Mond
VI IV III II V

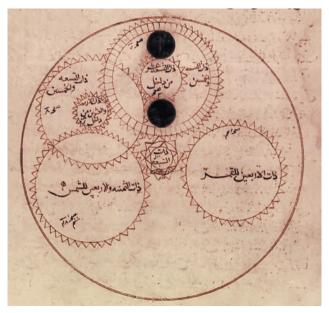
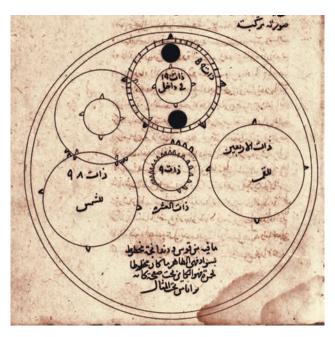



Fig. extraite de E. Wiedemann, op. cit.

[1] v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 6, p. 268.

[2] *Ein Instrument, das die Bewegung von Sonne und Mond darstellt, nach al Bîrûnî*, in: Der Islam (Strasbourg) 4/1913/5–13 (reprint in: E. Wiedemann, *Gesammelte Schriften*, vol. 2, pp. 718–726); Donald R. Hill, *Al-Bīrūnī*'s *Mechanical Calendar*, in: Annals of Science (London) 42/1985/139–163.

Al-Bīrūnī, *Istīʿāb*, MS Ahmet III, 3505.

Al-Bīrūnī, *Istīʿāb*, MS Leyde Or. 123 B.

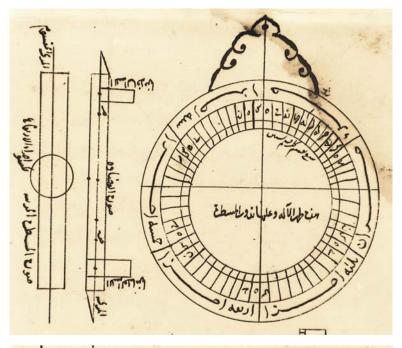
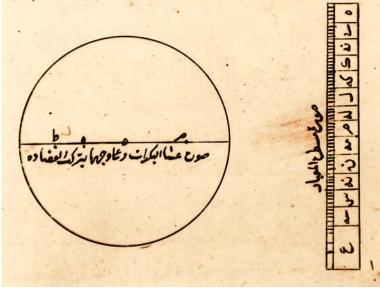
Al-Bīrūnī solves the task by means of the combined action of eight cogwheels with a transmission ratio of

7 : 10 : 19 : 24 : 40 : 48 : 59 : 59.

Our replica represents an approximate reproduction of the instrument as described by al- Bīrūnī; its perfect form becomes intelligible through an extant version by Muḥammad b. Abī Bakr al-Iṣfahānī (below) from the year 618/1221. Al- Bīrūnī does not claim to be the inventor of the instrument. He merely lays claim to the improvement of the mutual ratio of the cogwheels. Among his predecessors he mentions Basṭūlus[3] (Muḥammad b. Muḥammad al-Asṭurlābī) and al-Ḥusain b. Muḥammad Ibn al-Ādamī[4].

Al-Bīrūnī, *Istīʿāb*, MS Carullah 1451

[3] Lived in the second half of the 3rd/9th century, v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 6, pp. 178–179, 288

[4] Died probably around the turn of the 3rd/9th to the 4th/10th century, v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 6, pp. 179–180.

Instrument
for Determining the Altitude of Stars in Minutes

Our model:
Brass, etched,
cogwheels and gear-rim of steel,
diameter: 170 mm.
Gear drive with 5 cogwheels
and 2 balance cogwheels,
transmission ratio 1 : 60.
(Inventory No. A 2.21)

Figures from MS İstanbul, University Library, A.Y. 314.

Zainaddīn ʿUmar b. Sahlān as-Sāwī, who officiated as judge in Nīsābūr in the first half of the 5th/11th century, [1] bequeathed to us a hitherto unknown treatise on an instrument with which the altitudes of stars can be found correct to a minute. The text is called *Ṣifat āla yūṣal bihā ilā maʿrifat irtifāʿ al-kawākib bi-daqāʾiq*. It is preserved in a single manuscript in Istanbul[2] that was recently made accessible through a facsimile edition published by the Institute for the History of Arabic-Islamic Science in Frankfurt. The result of the measurement found in degrees through the alidade and the degree scale of the astrolabe on the front of the apparatus is transmitted, according to the inventor, to the back of the device, by means of built-in cogwheels, where one can read off the minutes by means of one more pointer.

The transmission gearing consists of five cogwheels and two balance cogwheels (*muʿaddila*), whose exact diameters are given.[3] The outermost cogwheel moves within the inner edge of the astrolabe in a gear-rim and covers 90° in each quadrant. The alidade moves around the axis of the central cogwheel. When it is moved up or down in the circle of degree divisions, the pointer at the back also turns and shows the subdivisions in minutes.

[1] Ẓahīraddīn ʿAlī b. Zaid b. Abi l-Qāsim al-Baihaqī, *Tatimmat Ṣiwān al-ḥikma*, Lahore 1354/1935, pp. 127–129; C. Brockelmann, *Geschichte der arabischen Litteratur*, Suppl., vol. 1, Leiden 1937, pp. 830–831.

[2] Istanbul, University Library, A.Y. 314, facsimile edition, *Manuscript of Arabic Mathematical and Astronomical Treatises*, Frankfurt 2001, pp. 196–212.

[3] Facsimile edition, pp. 202–203.

Mechanical-Astronomical
Calendar

by Muḥammad b. Abī Bakr al-Iṣfahānī

Al-Bīrūnī's mechanical-astronomical calendar lives on, with some further development, in a version dating from 618/1221 by a certain Muḥammad b. Abī Bakr al-Iṣfahānī. The original[1] of this model is in the Museum of the History of Science in Oxford (No. 1221-22, CCL 5). Our institute owns two replicas that were made on the basis of the original; the first one of these is closer to the original.
The spider carries the positions of 39 fixed stars. The only disc is meant for the latitudes 30° and 34°. The not visible gear-mechanism functions with eight cogwheels. Of the annular rings in the lower half of the back, the outermost one is meant for the zodiac signs, the second for the 30 days of the lunar month, the third is divided into 360°, the movable fourth ring shows the position of the Sun and the fifth the position of the Moon. The disc divided into black and white areas at the top of the back shows the daily waxing or waning of the Moon. The small window next to it tells the date.
It is worth noting that Derek J. de Solla Price,[2] in his study of 1959 on the origin of the clockwork, drew attention to a possible connection between the mechanical-astronomical instruments of the Arabic-Islamic world and the mechanical-astronomical devices appearing in the Latin world since Richard of Wallingford[3] (1st half of the 14th c.). While suggesting this, Derek Price relied primarily on the great similarity between the French-Gothic cogged wheel astrolabes (below, p. 170) and the same of Muḥammad b. Abī Bakr al-Iṣfahānī.

[1] R.T. Gunther, *The Astrolabes of the World*, Oxford 1932, p. 118; J. Vernet and J. Samsó (eds.), *El Legado Científico Andalusí*, Madrid 1992, p. 209.

[2] *On the Origin of Clockwork, Perpetual Motion Devices, and the Compass*, in: Contributions from the Museum of History and Technology, Washington 1959, p. 82–112, esp. p. 96, No. 6.

[3] On him, v. *Richard of Wallingford. An Edition of his Writings with Introduction, English Translation and Commentary* by J.D. North, 3 vols., Oxford 1976.

First Model,

made by
Eduard Farré (Barcelona)

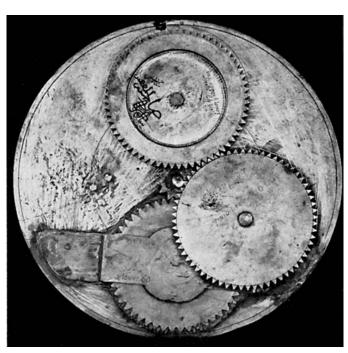
Diameter: 18,5 cm.
Brass, engraved.
(Inventoty No. B 3.07)

Second Model,

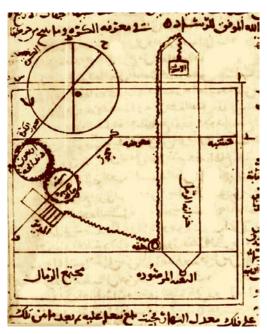
made by
Martin Brunold
(Abtwil, Schweiz)

Diameter: 12 cm.
Brass, engraved.
(Inventoty No. B 3.06)

French–Gothic Mechanical Calendar

Our model:
Brass, etched.
Diameter: 133 mm.
(Inventory No. B 3.15)

With great probability the calendar emerged from the tradition that we know now from a description by al-Bīrūnī (above, p. 164) and from the mechanical-astronomical calendar by Muḥammad b. Abī Bakr al-Iṣfahānī. The great similarity between the gear mechanism of the French-Gothic calendar and that of Muḥammad b. Abī Bakr al-Iṣfahānī was already pointed out by Silvio A. Bedini and Francis R. Maddison.[1]

Gear mechanism of the instrument by Muḥammad b. Abī Bakr al-Iṣfahānī.

[1] *Mechanical Universe. The Astrarium of Giovanni de' Dondi*, in: Transactions of the American Philosophical Society (Philadelphia), N.S., vol. 56 (1966), part 5, p. 10.

What is particularly remarkable about the French-Gothic instrument is that the double digit numbers of the days of the month are written from right to left, creating the impression as if the imitator had attempted to reproduce with his numerals the Arabic numerals, without, however, knowing that these are written from left to right contrary to the direction of the common Arabic mode of writing.

Additional literature: Gunther, *The Astrolabes of the World*, p. 347; Derek J. de Solla Price, *On the Origin of Clockwork*, op. cit., pp. 104–105; on the back of the instrument, v. D. A. King, *The Ciphers of the Monks. A Forgotten Number-Notation of the Middle Ages*, Stuttgart 2001, p. 402.

Gear-mechanism of the French-Gothic calendar in its present state of preservation..

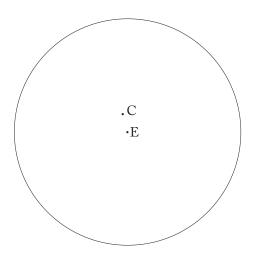
Drawing from MS Damascus, Ẓāhirīya 4871.

Our functional model:
Globe of brass,
diameter: 25 cm.
Height of the glass tube: 80 cm.
Brass stand: 45 × 65 × 85 cm.
(Inventory No. B 3.02)

The Instrument

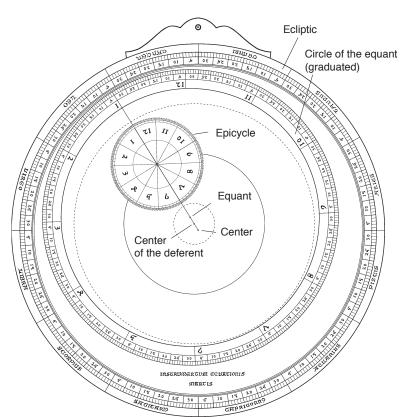
with the Sphere that turns uniformly around itself

The astronomer and instrument maker Muḥammad b. Aḥmad al-Ḫāzimī (made observations in Isfahan around 453/1061) describes this device in a treatise on the "Construction of a globe which turns in uniform motion around itself, according to the motion of the celestial sphere" (*Maqāla fī ttiḫāḏ kuratin tadūru bi-ḏātihā bi-ḥaraka mutasāwiya li-ḥarakat al-falak*). A celestial globe with constellation figures, the ecliptic and the celestial equator is brought to uniform rotation as follows: Through a glass tube sand trickles down through a regulated nozzle and lets a weight resting on the sand sink downwards. A rope attached to the weight causes, through gears, the globe to turn once around on its own axis while the sand trickles out completely within 24 hours (in our model the process is accelerated). The time can be read off with a precision of four minutes on a scale that encloses the equator on the stand.

[1] The treatise is preserved in two manuscripts, v. R. Lorch, *Al-Khāzinī*'s *‹Sphere that Rotates by Itself›*, in: Journal for the History of Arabic Science (Aleppo) 4/1980/287–329; F. Sezgin (ed.), *Manuscript of Arabic Mathematical and Astronomical Treatises* (facsimile of MS Istanbul, University Library, A.Y. 314), Frankfurt 2001, pp. V–VI.

Equatoria

The equatorium (from Latin *æquatio*, equation) is an astronomical instrument that began to make its appearance in the second half of the 13th century A.D. in Europe outside of Spain. To judge from the numerous extant descriptions, it enjoyed wide dissemination and remained in circulation in many forms until the 17th century. It is however surprising that until the second half of the 20th century hardly any historian of astronomy directed his attention to this instrument. The interest in the equatorium and its history was aroused only after the publication of a series of articles written by E. S. Kennedy[1] since 1947 on a text he had discovered by Ġiyāṯaddīn Ǧamšīd b. Maḥmūd al-Kāšī (d. ca. 838/1435) which describes the two instruments *ṭabaq al-manāṭiq* ("ecliptic disc") and *lauḥ al-ittiṣālāt* ("plate of conjunctions"), the first of which represents the highest development of the instrument generally known as the equatorium in Europe. Kennedy also deserves credit for being the first to connect the European equatorium with al-Kāšī's instrument,[2] or rather with an Arabic-Islamic prototype. The impact of Kennedy's writings led in the second half of the 20th century to a substantial enhancement of our knowledge of the instrument, its origin, its development and its significance.

Just a short while afterwards, an important contribution *The equatorie of the planetis* by Derek J. Price[3] was published with a facsimile edition, a translation in modern English, and a commentary, of the work on the equatorium (written ca. 1392, ascribed to Geoffrey Chaucer)—one of the most significant studies on the subject in the Occident. Price also discussed the history of the instrument, which deserves our gratitude.

The equatorium serves primarily for the geometric determination of the longitudes of the planets, the Sun and the Moon on the ecliptic according to the Ptolemaic geocentric model. Astronomers realised quite early that, observed from the Earth as the assumed centre of the universe, the angular velocity of the planets is not constant. This led to the assumption of eccentric circular orbits of the planets around the Earth with additional epicyclic rotations of the planets on the eccentric supporting orbits. The originator of this idea was probably Apollonius of Pergae.

E = centre of the Earth
C = centre of the eccentric orbit or deferent.

[1] E.S. Kennedy, *Al-Kāshī's ‹Plate of Conjunctions›*, in: Isis (Cambridge, Mass.) 38/1947–48/56–59; idem, *A Fifteenth-Century Planetary Computer: al-Kāshī's ‹Ṭabaq al-Manāṭeq›. I. Motion of the Sun and Moon in Longitude*, in: Isis 41/1950/180-183 and *II. Longitudes, Distances, and Equations of the Planets*, in: Isis 43/1952/42–50; idem, *A Fifteenth-Century Lunar Eclipse Computer*, in: Scripta Mathematica (New York) 17/1951/91–97; idem, *An Islamic Computer for Planetary Latitudes*, in: Journal of the American Oriental Society (Ann Arbor) 71/1951/13–21 (reprint of all the articles in: *Studies in the Islamic Exact Sciences,* by E.S. Kennedy, colleagues and former students, Beirut 1983, pp. 448–480).

[2] E.S. Kennedy, *A Fifteenth-Century Planetary Computer*, p. 50 (reprint p. 480).

[3] *The Equatorie of the Planetis*. Edited from Peterhouse Ms. 75.I by Derek J. Price, with a linguistic analysis by R.M. Wilson, Cambridge 1955.

Ptolemy for his part succeeded in "keeping the hitherto existing eccentric circle as equant and letting a point in the same move uniformly–introducing, however, as the deferent, or carrier of the epicycle, a second circle which was equal to the former and whose centre was at the middle distance of the Earth and of the equant centre, and from which he transferred each of the positions m, obtained for specific periods of time in the equant, to M on the deferent."[4] The Ptolemaic model, which the Arab astronomers criticised since the 4th/10th century for violating the principle of the uniformity of angular velocity and which they had tried to replace with other models, is characterised by three principles:

1. The centre of the epicycle moves on the deferent from the west to the east.
2. Its angular velocity is constant in relation to the equant, hence variable on the deferent.
3. The planet moves with the same angular velocity in the opposite direction around the centre of the epicycle.[5]

The equatorium represents the orbits by means of movable parts, mostly discs cut out of brass. Then the actual position of a planet on its epicycle, found geometrically (not by computation) from the tabulated basic values, is projected upon the ecliptic (with a ruler, or with the alidade or threads). In al-Kāšī's model, this part is omitted, the values of the epicycles being also engraved on the reference disc are projected with an ingenious apparatus of the parallels. An essential feature of the development is, therefore, the rationalisation of what was originally a rather unwieldy instrument.

Remarkably enough already in the early Andalusian instruments of az-Zarqālī and Abu ṣ-Ṣalt, the Mercury model with its variable centre of deferent is represented with a resultant, ellipse-like deferent.

The equatoria known or preserved so far and their descriptions display remarkably divergent forms and show that the instrument underwent a certain development both in the Arabic-Islamic world and in the Occident. What is particularly striking is that it enjoyed much greater popularity in the Occident than in the region of its origin.

Model of Mars after Ptolemy, as envisaged in the equatorium of Campanus (below).

[4] Rudolf Wolf, *Handbuch der Astronomie, ihrer Geschichte und Litteratur*, Zurich 1890–91, reprint Hildesheim 1973, vol. 1, p. 530.

[5] Cf. *Campanus of Novara and Medieval Planetary Theory. Theorica planetarum*, ed. with an introduction, English translation and commentary by Francis S. Benjamin and G.J. Toomer, London 1971, pp. 39 f.

D. J. Price, who was the first to attempt a description of the historical development of the equatorium, could trace its origin back to the Andalusian astronomer Abu l-Qāsim Aṣbaġ b. Muḥammad Ibn as-Samḥ[6] (d. 426/1035).[7] According to the present state of our knowledge, the great mathematician and astronomer Abū Ǧaʿfar Muḥammad b. al-Ḥusain al-Ḫāzin (fl. ca. 350/960)[8] seems to be the inventor of the instrument which he, for his part, called *Zīǧ aṣ-ṣafāʾiḥ* (table in the form of discs). Extant components of such an instrument and a manuscript, discovered in the last few years, of the voluminous astronomical work by Abʿ Ǧaʿfar al-Ḫāzin, which is also called *Zīǧ aṣ-ṣafāʾiḥ*, let us assume that he was indeed the inventor of the instrument (below, p. 177).

To judge from the surviving traces, the instrument or its description reached Andalusia rather early. Credit goes to Alfred Wegener for having, at the beginning of the 20th century, discovered and examined a Castilian translation of the treatise by the above mentioned Ibn as-Samḥ and of a work by Ibrāhīm b. Yaḥyā az-Zarqālī (late 5th/11th c.) in the Alfonsine *Libros del saber de astronomía*[9] (ca. 1277)[10]. One more description, originating from Andalusia, of the instrument based on the Arabic original by Abu ṣ-Ṣalt Umaiya b. ʿAbdalʿazīz b. Abi ṣ-Ṣalt (d. 529/1135) was made known in 1970 by E. S. Kennedy (below, p. 185).

Kennedy made his most important contribution to the elucidation of the history of the equatorium through the discovery of the book by the above mentioned Ġiyāṯaddīn Ǧamšīd b. Masʿūd al-Kāšī and tby editing and studying the text. Al-Kāšī calls the instrument *ṭabaq al-manāṭiq*, while it is simply called *ṣafīḥa* ("disc") by the Andalusian scholars mentioned previously. The instrument for the determination of the longitudes of the planets on the ecliptic described by al-Kāšī turns out to be the altogether highest development of the type. With it it was also possible to find the latitudes of the planets. Besides, al-Kāšī describes a second instrument in his book, which he calls *lauḥ al-ittiṣālāt*. It was used to determine the conjunctions of the planets (below, p. 196).

The oldest known European description of the equatorium did not come from Spain or other early centres of the reception and assimilation of Arabic-Islamic sciences like France and England, but from Italy. It is to be found in the *Theorica planetarum* by Giovanni Campano de Novara (2nd half of the 13th c.). Even if the treatment of the material in the *Theorica* cannot be directly connected, for chronological reasons, to the Arabic-Islamic descriptions known to us or their Castilian versions, we must not allow ourselves to be deceived by the assurance given in the introduction on the author's originality. If such an instrument did not itself reach his knowledge from the Islamic world through the mediation of crusaders or perhaps via Spain, then we can assume with certainty that the Latin translation of at least a special treatise on the instrument or another source on the subject were at the disposal of Campanus of Novara.[11] The description in the *Theorica* of Campanus, written between 1261 and 1264 and dedicated to Pope Urban IV, found its next important successor in the *Abbreviatio instrumenti Campani, sive aequatorium* by the well-known Johannes de Lineriis (Jean de Linières or Lignières, writing in 1320).[12]

[6] Although Price (op. cit., p. 120) points out a device for the determination of the centre point of the Sun, which Proclus Diadochus (ca. 450 AD) described in his *ὑποτύπωσις τῶν ἀστρονομικῶν ὑποθέσεων*, he is of the opinion that this device cannot be equated with the equatorium.

[7] v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 5, p. 356; vol. 6, p. 249.

[8] v. ibid., vol. 5, pp. 298–299, 305–307; vol. 6, pp. 189–190.

[9] vol. 3, ed. Manuel Rico y Sinobas, Madrid 1864 (reprint in: Islamic Mathematics and Astronomy vol. 111), pp. 241–284.

[10] A. Wegener, *Die astronomischen Werke Alfons X*, in: Bibliotheca Mathematica (Leipzig), 3. F. 6/1905/129–185, esp. pp. 152–161 (reprint in: Islamic Mathematics and Astronomy vol. 98, pp. 57–113, esp. pp. 80-89).

[11] G.J. Toomer, who published, translated and investigated, together with Francis S. Benjamin, the *Theorica planetarum* (Madison 1971), says in this connection: «I believe that he owes the idea to some hitherto undiscovered Arabic-Latin source» (Dictionary of Scientific Biography, vol. 3, New York 1971, p. 27, s.v. Campanus).

[12] v. G. Sarton, *Introduction to the History of Science*, vol. 3, pp. 649–652; Emmanuel Poulle in: Dictionary of Scientific Biography, vol. 7, New York 1973, pp. 122–128.

The West's preoccupation with the equatorium, which began with Campanus of Novara, enthused occidental scholars time and again up to the 16th century. The impact this interest had on literature and on instrument making is discussed at length by Emmanuel Poulle in his *Équatoires et horlogerie planétaire du XIIIe au XVIe siècle* (2 vols., Geneva and Paris 1980). In this work, however, the question of the Arabic origin of those activities is dealt with too briefly. Although he traces the origin of the European instrument back to the Arabic-Islamic cultural sphere, the Arabist G. J. Toomer creates the impression of seeing this process as limited to the solitary mediation through Campanus of Novara and of treating the subsequent development as an inner-European matter without further assistance from the region of origin, when he says: "The history of that instrument after Campanus is a good illustration of the technical ingenuity of the astronomy of the late Middle Ages and early Renaissance."[13] By contrast, I am convinced that the instrument and texts with its description extended many times from the Arabic-Islamic area to Europe and influenced the further development there. When we see, for instance, that Campanus of Novara, like Ibn as-Samḥ, uses one disc each, that is to say, all in all seven discs for the computation of planetary longitudes, and that his immediate successor Jean de Lignières operates with a single disc as Abu ṣ-Ṣalt and az-Zarqālī did on the Arab side, then the conjecture is inescapable that, besides the *Theorica* of Campanus, the younger scholar must have had access to additional sources or models from the Islamic world.

Thus the equatorium is a concrete example of the process of continuity of Arabic-Islamic sciences in Europe, through which we can understand how an instrument, when it once became known, preoccupied technicians and inspired astronomers over centuries. The equatorium as such is not of special importance; the results it generates could be obtained more accurately from computation (at least in the Islamic world). Although Europe did not reach the level which we know from al-Kāšī's model, the extant instruments and the illustrations did testify to a fast developing technology that was set to overtake its precursor in the Islamic world, on any account faster than this happened in the theoretical field. Typical of this is the fact that the knowledge of the precession of the apogee, known in the Arabic-Islamic world since the 3rd/9th century, only made its appearance in Europe in the first half of the 16th century through one of the writings on the equatorium, namely the work by Johannes Schöner.

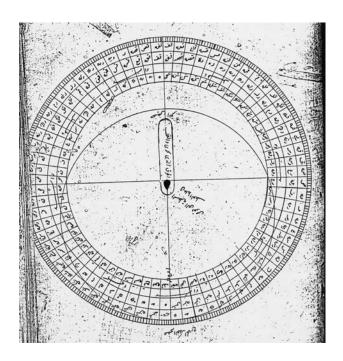
[13] In: Dictionary of Scientific Biography, vol. 3, p. 27.

Equatorium
by Abū Ǧaʿfar al-Ḫāzin

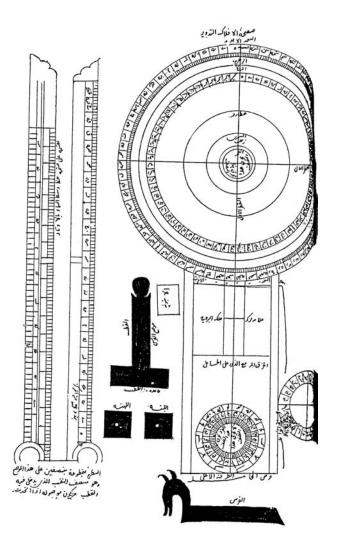
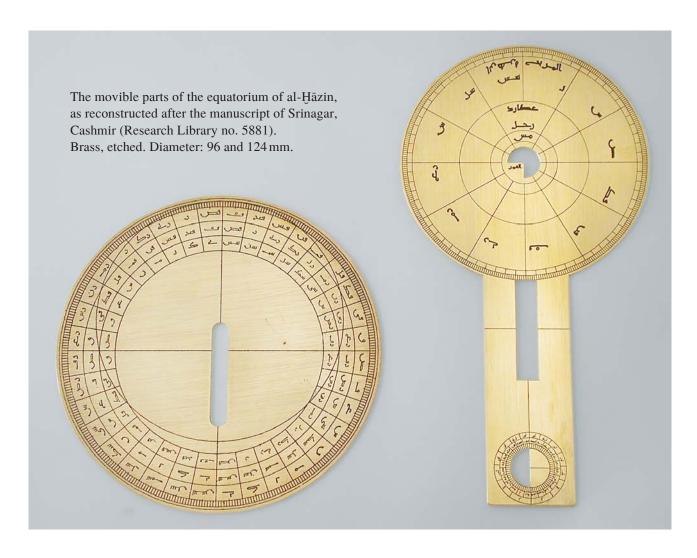
Our model:
Brass, etched.
Diameter: 260 mm.
(Inventory No. A 6.01)

That the famous mathematician Abū Ǧaʿfar Muḥammad b. al-Ḥusain al-Ḫāzin (fl. first half of the 4th/10th c., above, p. 175) is the inventor of the equatorium, so widespread in Europe between the 13th and 16th centuries, is now established beyond doubt. He called his instrument *zīǧ aṣ-ṣafāʾiḥ* and described it in his book of the same name. The single extant specimen of such an instrument was in the collection Paul Klostermann in Munich in around 1920. Photographs of the instrument—which is believed to be lost—from the archives of D. J. Price (Yale) were recorded by Francis Maddison and Anthony Turner in their *Catalogue of an Exhibition*[1] under the title "A *zīǧ* on the plate of an astrolabe A. H. 513-514 (A.D. 1119/20-21)". While examining the photographs, they noticed further that the specimen is signed by the noted astrolabe maker Hibatallāh b. al-Ḥusain al-Baġdādī, who referred to Abū Ǧaʿfar al-Ḫāzin, but reworked the instrument.

In his study of the three published photographs, David King[2] came to the conclusion that it was an early equatorium, but attributed the present specimen to Hibatallāh al-Baġdādī. At some time or other the instrument must have reached Berlin, where it is now in the possession of the Museum für Indische Kunst.[3] Extant are the mater with an astrolabe disc engraved on the front for the latitude of Raiy; a rete which, however, is likely to be a later replacement; a disc that is inserted into the recess at the back of the mater, as well as an alidade. [179] The back of the mater bears an engraved *zīǧ* table.

[1] *‹Science and Technology in Islam›, held at the Science Museum, London. April–August 1974 in association with the Festival of Islam*. The catalogue was prepared in 1976, but has not yet been published; I have a hectograph copy, see pp. 184 ff.

[2] *New Light on the Zīj al-Ṣafāʾiḥ of Abū Jaʿfar al-Khāzin*, in: Centaurus (Copenhagen) 23/1980/105–117.

[3] I owe this information to my colleague David King.

[178] Our model, above: The *umm* with *zīǧ* engraving (longitudes of the planets) on the surface.
Below: The *umm* with disc, *zīǧ* engraving (latitudes of the planets).

One side of the disc contains a four-fold quadrant (used for trigonometric computations together with the alidade), the other side is the *zīǧ* disc proper with a table of the mean latitudes (sic!) of the planets (i.e. Sun, Moon and the five planets). Thus the front of the instrument offers a conventional astrolabe and the back can be used as an equatorium, although, unfortunately, the necessary additional components (deferent disc, epicycle) are missing. A small upraised ring attached around the disc on the *zīǧ* side seems to have been intended for holding these components, especially in transport, by forming a suitable recess when the disc is inserted with the quadrant to the outside. The *zīǧ* disc has numerous dot-like depressions in a concentric circle, and two each on the Auges (aspsidal lines) of the planets; these apparently made it possible to lock these components into place there. Hibatallāh al-Baġdādī explains in an inscription that he modified this apparatus vis-à-vis al-Ḫāzin's text, but a reconstruction is not possible at this time. It is however very fortunate—not only for the history of Arabic astronomy—that a manuscript copy of the book *Zīǧ aṣ-ṣafā'iḥ* by al-Ḫāzin was discovered a short while ago in the Research Library, Srinagar, Kashmir (No. 5881). Unfortunately, this text too contains lacunae; only one page of the description and a few figures of the equatorium proper have been preserved. But according to these, it is clear that what we have here is a question of a fully mature—in fact, highly advanced—type of equatorium.

From the text fragment and the two extant figures (see illustration on the right) we can for the present draw the following conclusions:

A disc graduated with three scales defines the common equant/deferent of the planets. The clockwise scale serves to determine the longitude of Mercury and the anticlockwise scale those of the remaining planets. An eccentric circle represents the rotating deferent of the Moon. An incised window is provided for the pin, running from the centre in the direction of the perigee, which makes it possible to adjust the eccentricity to the respective planet (this seems very ingenious in comparison to the many [**180**] graduated circles of most of the later equatories); however, it is not quite clear yet how this was projected onto the deferent (perhaps by means of a parallel ruler). The common disc of the epicycles, which can likewise be rotated on the pin through an oblong incised window, is placed on this disc. This

Figures from MS Srinagar, nº 5881.

The movible parts of the equatorium of al-Ḫāzin, as reconstructed after the manuscript of Srinagar, Cashmir (Research Library no. 5881). Brass, etched. Diameter: 96 and 124 mm.

common disc also has a clockwise and a anticlockwise graduation from which the mean argument is read, after the centre of the epicycles (likewise incised) has been positioned on the measured angle of the first disc.

By means of the alidade, set up from the centre of the instrument across the location of the planet on the epicycle, the planet's true longitude can then be read off the limb.

We took pains to construct the extant components of the instrument as advanced by Hibatallāh al-Baġdādī and also attempted to reconstruct, on the basis of the conclusions reached from al-Ḫāzin's text which we discussed above, the eccentric circle and the epicycle instrument, although for al-Baġdādī's later model a modified apparatus was envisaged.

The question remains open as to why exactly Abū Ǧaʿfar al-Ḫāzin, who rejected—according to clear statements by al-Bīrūnī—the Ptolemaic models of eccentricity and epicycles and replaced them with the assumption of variations of the respective planetary orbits up to the plane of the ecliptic,[4] invented an instrument which faithfully reflects the Ptolemaic model. To this question I have only one answer at present, namely that the book *Zīǧ aṣ-ṣafāʾiḥ* probably dates from an earlier phase in Abū Ǧaʿfar al-Ḫāzin's intellectual development, when he had not yet cast doubts on the correctness of the Ptolemaic representation.

[4] v F. Sezgin, op. cit., vol. 6, p. 189.

Our model:
Brass, etched.
Diameter: 275 mm.
(Inventory No. A 6.12)

Equatorium
by Ibn as-Samḥ

The mathematician and astronomer Abu l-Qāsim Aṣbaġ b. Muḥammad Ibn as-Samḥ al-Ġarnāṭī (d. 426/1035)[1] offers us the earliest known Andalusian description of the instrument invented by Abū Ǧaʿfar al-Ḫāzin; unfortunately, this description has come down to us only in its Castilian translation, viz. as the first of the two books of the "Discs of the Seven Planets" in the *Libros del saber de astronomía*,[2] compiled at the behest of Alfons X (d. 1284).

The description of the instrument in the Castilian translation is unsatisfactory, with the mix up between the deferent centre and the equant, perpetuated in all planetary models (except Mercury), through which the instrument would lose its practical value being particularly irritating. We assume therefore that it is a later corruption (presumably in the translation) and have corrected the construction in accordance with the Ptolemaic model.

[1] v. F. Sezgin, op. cit., vol. 5, p. 356, vol. 6, p. 249.
[2] M. Rico y Sinobas (ed.), *Libro I de las láminas de los vij. planetas,* in: *Libros del saber…*, vol. 3, pp. 245–271.

Ibn as-Samḥ allots for each planet a separate disc with a common mater (on the back of which the solar model is engraved), as is a common epicycle disc which is engraved with diverse radii. Each instrument consists of a graduated deferent and a ring laid concentrically around the deferent, against which the edge of the epicycle disc is positioned. Both scales are divided into graphically unequal degrees, which were projected by the respective equants. The lunar model and the Mercury model are equipped with discs that can be rotated in order to take the movable deferent into account.[3] If this construction seems to be a backward step in comparison to al-Ḫāzin's model, the reason may be that al-Ḫāzin's original text was not available to Ibn as-Samḥ and that the Andalusian development was inspired by a secondary text or an instrument from the east of the Islamic world.

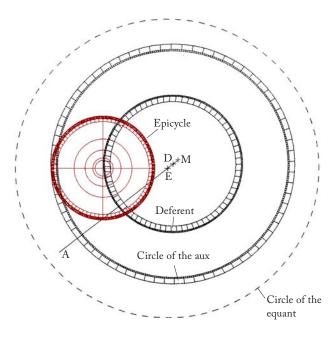
We have endeavoured in our model to reconstruct the original condition of Ibn as-Samḥ's Arabic instrument.

[3] A. Wegener, *Die astronomischen Werke Alfons X.*, in: Bibliotheca Mathematica (Leipzig) 3. F. 6/1905/129–185, esp. pp. 152–155 (reprint in: Islamic Mathematics and Astronomy, vol. 98, pp. 57–113, esp. pp. 80–83); J.L. Mancha: *Sobre la version alfonsí del equatorio de Ibn al-Samḥ*, in: M. Comes, R. Puig & J. Samsó (eds.), *De astronomia Alfonsi Regis*, Barcelona 1987, pp. 117–123; J. Samsó, *Notas sobre el ecuatorio de Ibn al-Samḥ,* in: *Nuevos estudios sobre astronomía española en el siglo de Alfonso X*, Ed.: J. Vernét, Barcelona 1983; M. Comes, *Ecuatorios andalusíes*, Barcelona 1991; idem, *Los ecuatorios andalusíes,* in: El legado científico Andalusí, Madrid: Museo Arqueológico Nacional, Madrid 1992, pp. 75–87.

aṣ-Ṣafīḥa az-zīğīya

(Equatorium) by az-Zarqālī

Our model:
Brass, etched.
Diameter: 275 mm.
(Inventory No. A 6.02)

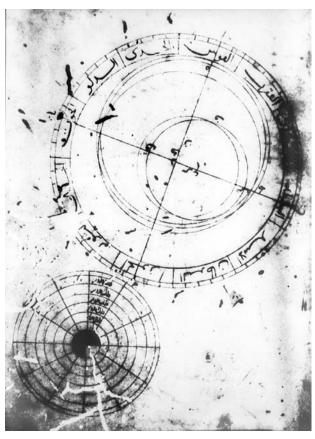
Besides writing a treatise on the universal disc which is named after him (*aṣ-ṣafīḥa az-Zarqālīya*), the great astronomer and mathematician from Toledo, Abū Isḥāq Ibrāhīm b. Yaḥyā az-Zarqālī (Castilian: Azarquiel, fl. 2nd half of the 5th/11th c., above, p. 175), probably wrote two treatises on the instrument which came to be known in Europe later as the equatorium (called by him *aṣ-ṣafīḥa az-zīğīya*); one of the treatises deals with the use of the instrument and the other with its construction. At present, only the first is known in the original[1] and was partly edited and completely translated into Spanish by José Millás Vallicrosa.[2]

This text, however, differs greatly from the Castilian translation in the *Libros del saber de astronomía*.[3] It is yet to be investigated whether, besides the manuscript of the British Library used by Millás Vallicrosa, the other two known manuscripts in Leiden,[4] whose scope seems to be substantially larger, are possibly identical with the version used in the Castilian translation. The instrument described by az-Zarqālī displays a considerably more advanced stage of development than that of Ibn as-Samḥ, although a few peculiarities of the latter instrument seem to have been adapted.

[1] MS British Library, Add. 1473, ed. M. Comes, *Ecuatorios andalusíes*, Barcelona 1991, pp. 203–221.
[2] In his *Estudios sobre Azarquiel*, Madrid–Granada 1943–1950, pp. 458–483.
[3] M. Rico y Sinobas (ed.), op. cit., vol. 3, pp. 272–284.
[4] Or. 993/1 (fol. 1–20), Or. 1876/3 (63[a]-82[a]) v. *Handlist of Arabic Manuscripts in the Library of the University of Leiden and other Collections in the Netherlands*, compiled by P. Voorhoeve, Leiden 1957, p. 12.

Back of the instrument after the Castilian version in the *Libros del saber de astronomía*, MS cod. 156 Universidad Complutense.

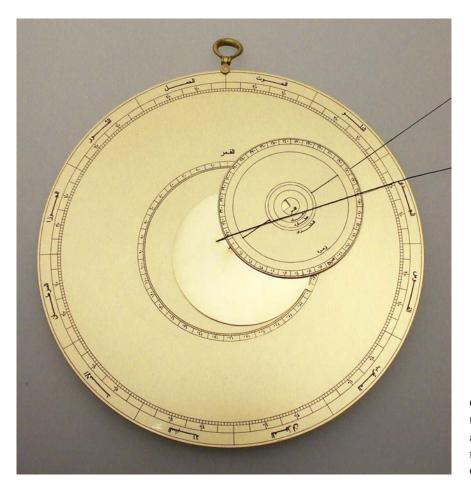
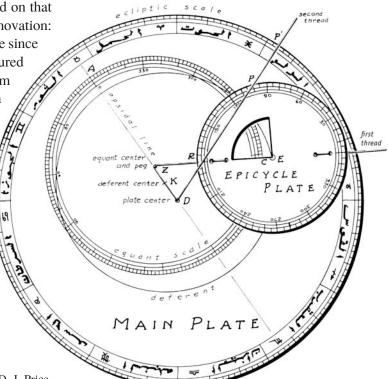
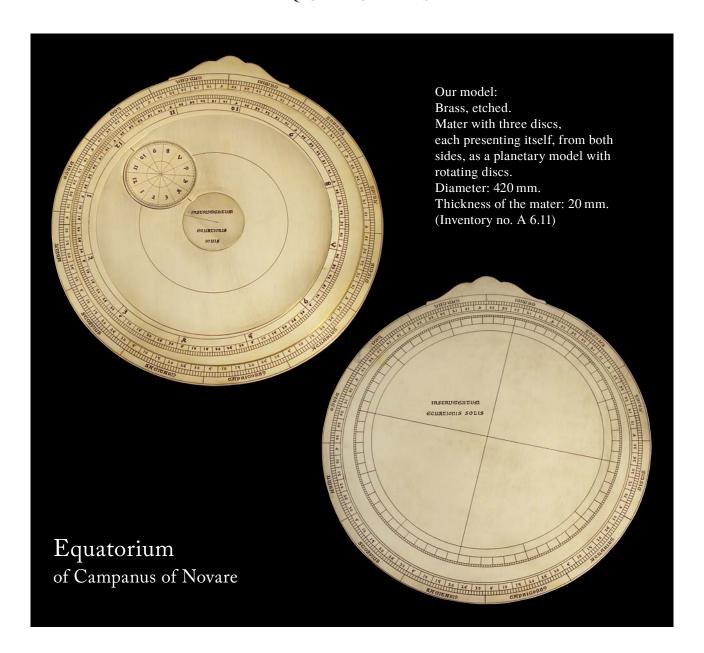
Equatorium of az-Zarqālī, diagram of the projection for Saturn, A: aux of the planet to be calculated, E: equant, D: centre of the deferent, M: centre of the ecliptic.
After M. Comes, *Ecuatorios andalusíes*, op. cit., p. 98, fig. 26.

Az-Zarqālī manages with two sides of one disc and a separate epicycle disc for determining the true longitudes of the five planets, of the Sun and of the Moon. For this purpose, the deferents with 'aux-circles' are engraved within each other, with the radii shortened towards the inside (the epicycle radii have been modified accordingly). But this reduces the precision of measurement that can be achieved by the same degree. As in the case of Ibn as-Samḥ's model, the graduations are transferred to the two circles with an equant circle—which was later discarded—so that the graphically different degrees on the deferent represent uniform angular velocity around the equant. The aux-circles constitute in each case the outer limit of the sphere of a planet and serve for the adjustment of the mean aux (*auǧ*, apogee) of the epicycle. The method of graduating all seven deferents and their aux-circles separately, instead of performing all the angle measurements by shifting parallels at the common limb as is done in the later models, leads, however, to a rather complicated instrument. The deferent of Mercury is executed for the first time as a resultant ellipse-like figure from the motion of the deferent centre upon its additional orbit.

Cf. M. Comes, *Ecuatorios andalusíes*, pp. 79–138; E. Poulle, *Équatoires et horlogerie planétaire du XIII[e] au XVI[e] siècle*, op. cit., pp. 194–200 and passim; D.J. Price, *The Equatorie of the Planetis*, Cambridge 1955, pp. 123 ff.

aṣ-Ṣafīḥa
(Equatorium)
by Abu ṣ-Ṣalt al-Andalusī

Our model (front with limb, deferents, aux-circles and epicycle, here arranged for the measurement of Mars):
Brass, etched.
Diameter: 275 mm.
With one epicycle disc.
Two threads.
(Inventory No. A 6.03)

The versatile Andalusian scholar Abu ṣ-Ṣalt Umaiya b. ʿAbdalʿazīz b. Abi ṣ-Ṣalt from Denia (460-529/1068-1135)[1] wrote, largely depending on az-Zarqālī, his description of an 'encompassing disc' (*ṣafīḥa ǧāmiʿa*) which was to serve for the determination of the true ecliptic longitude of the planets. E. S. Kennedy was the first to devote a comprehensive study[2] to the only known manuscript[3] and to furnish his study with his own diagrams of the instrument. Another study with an edition of the Arabic text and Spanish translation is credited to Mercè Comes.[4]

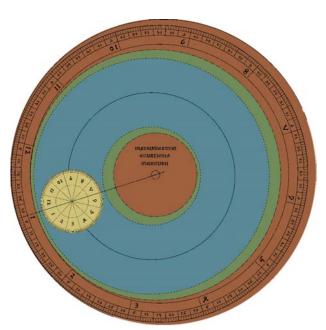
Fig. from the unfortunately much damaged MS Beirut. The incision at the centre of the epicycle can clearly be seen..

[1] v. C. Brockelmann, *Geschichte der arabischen Litteratur,* Suppl., vol. 1, p. 869.
[2] E. S. Kennedy, *The Equatorium of Abū al-Ṣalt*, in: Physis 12/1970/73-81.
[3] MS Beirut, Bibliothèque Orientale de l'Université St. Joseph, nº 223/17, pp. 131–137; cf. L. Cheikho in: Mélanges de la Faculté Orientale (Beirut) 7/1914–21/288.
[4] M. Comes, op. cit., pp. 139–157, 237–251.

Our model (back with Moon instrument): With epicycle disk and another disk, riveted movably, to represent the motion of the Moon deferent.

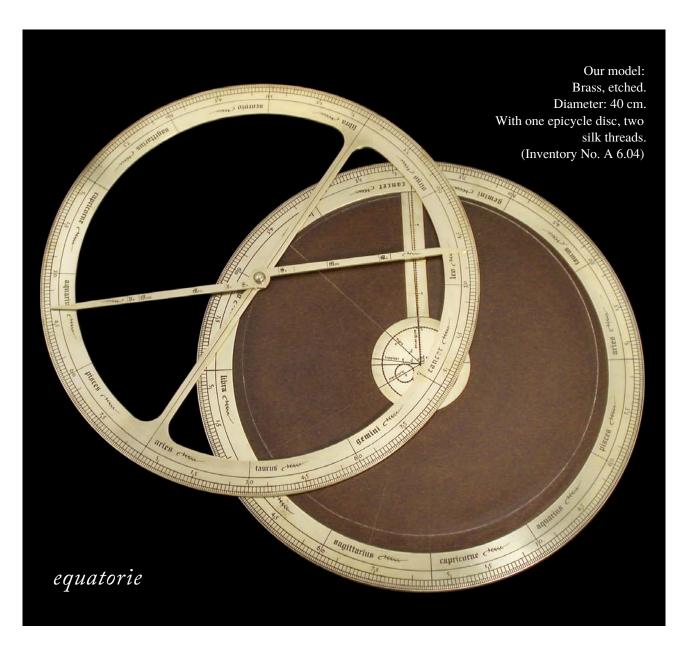
Abu ṣ-Ṣalt's equatorium is apparently based on that of az- Zarqālī, but it contains a substantial innovation: the deferents need not be graduated any more since the mean motions of the planets are measured at the equant circle and are projected from there to the centre of the epicycle, which is placed against the deferent by means of the first thread wound around a small peg at the equant centre. The diagram (on the right) by E. S. Kennedy shows the measurement of one of the outer planets. The second thread serves to project the true place of the planet on the epicycle (P) upon the ecliptic (with the Earth as the centre).

Fig. from E.S. Kennedy, *The Equatorium of Abū al-Ṣalt*, p. 76.

v. also: E. Poulle, op. cit., pp. 194-200 and passim; D. J. Price, op. cit., p. 123 ff.

Our model:
Brass, etched.
Mater with three discs,
each presenting itself, from both sides, as a planetary model with rotating discs.
Diameter: 420 mm.
Thickness of the mater: 20 mm.
(Inventory no. A 6.11)

Equatorium
of Campanus of Novare

Campanus of Novara (fl. 2nd half of the 13th c., above, p. 175) is the author of the *Theorica planetarum*[1] (ca. 1260), the earliest treatise in Europe beyond Spain—circulated in numerous copies—on the motion of planets and an instrument to be used for their determination. In his time he was considered an important mathematician and astronomer, although his works are very laborious, obscure and quite far removed from reality. These are basically compilations from Arabic sources, however, of a phase of development already rendered obsolete in his time; particularly the type of construction known to us through Ibn as-Samḥ can be considered as a model, although Campanus's instrument with its rotary discs placed one inside the other is still much more impractical than that by Ibn as-Samḥ. The development that could be seen somewhat belatedly in the Castilian *Libros del saber de astronomía* (ca.1277, above, p. 181) was still unknown to Campanus. The instrument consists–as that of Ibn as-Samḥ–of one disc each for each planet. These are inserted, as in an astrolabe, into one common mater (the solar model is also [**188**] engraved on the back of the mater here).

[1] v. Ed., Engl. transl. and commentary by F.S. Benjamin and G.J. Toomer, *Campanus of Novara and Medieval planetary Theory/Theorica planetarum*. Madison, Milwaukee and London 1971.

Left: Our model with the Moon/Mercury disc resting in the mater, above it the Saturn/Jupiter disc and the Mars/Venus disc.
Fig. below: Explanation of the use of the instrument by means of the Mercury model. In the red disc, which is fixed firmly, the green disc is pivoted, in which the blue (deferent) and the yellow disc (epicycle) are pivoted. By rotating the green, blue and yellow discs together, (taking the respective values from a table), the present position of the deferent centre in its orbit (the small circle in the middle) is set; after that the blue disc is rotated with the yellow one so that the aux corresponds to the mean value read off on the scale on the outer red ring (the equant). Then the mean argument is set by turning the epicycles and the ascertained true longitude of Mercury on its epicycle is transferred by means of a stretched thread to the common limb of the mater (not visible here), which corresponds to the ecliptic.

The epicycle discs are inserted so that they rotate in larger discs (which represent the motion on the deferent), which for their part are each inserted eccentrically into one further disc, which again is attached to a basic disc, either rotating (Mercury and Moon) or fixed. The measurements are done by means of threads attached to the discs.
Our reconstruction showed that the practical realisation of the instrument as described by Campanus probably went beyond the limits of what was possible in Europe at that time; in any case it is very cumbersome to have six instruments each with several discs rotating in each other, which are held firmly in one another by intersecting rims, especially since even the smallest deviation leads to the blockage of the whole apparatus. It is however likely that Campanus envisaged an instrument of gigantic dimensions.

Our model:
Brass, etched.
Diameter: 40 cm.
With one epicycle disc, two silk threads.
(Inventory No. A 6.04)

equatorie

Reconstructed after a Middle English treatise on the manufacture and use of the equatorium in the MS Cambridge, Peterhouse 75.I—the earliest on the subject in the English language—apparently from 1392 and usually ascribed to the poet Geoffrey Chaucer (ca. 1343-1400).[1] Since the 1970s it has been assumed that his instructive book for children on the astrolabe (*Bred & mylk for childeren*, ca. 1391) is based on the Latin translation of the treatise of the early Abbasid scholar Māšāʾallāh. Meanwhile it has been shown to be a certainty that Chaucer knew this text from a Latin compilation of the late 13th century.[2] In the second part, this compilation contains, moreover, a text whose author has been identified as the Andalusian astronomer[3] Aḥmad b. ʿAbdallāh Ibn aṣ-Ṣaffār (d. 426/1035).[4] A future comparison of the treatise by Ibn aṣ-Ṣaffār, preserved in the Arabic original as [**190**] well as

[1] v. D.J. de Solla Price, in: Dictionary of Scientific Biography, vol. 3, p. 217; J.D. North, *Chaucer's Universe*, Oxford 1988, pp. 42–45.

[2] v. P. Kunitzsch, *On the Authenticity of the Treatise on the Composition and use of the Astrolabe as Ascribed to Messahalla,* in: Archives Internationales d'Histoire des Sciences (Wiesbaden) 31/1981/42–62.

[3] P. Kunitzsch, op. cit., p. 46.

[4] v. F. Sezgin, op. cit., vol. 6, p. 250.

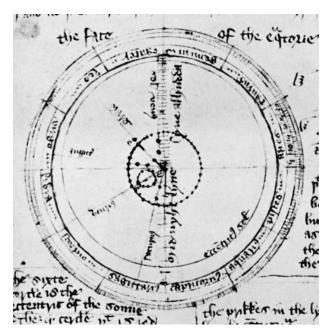
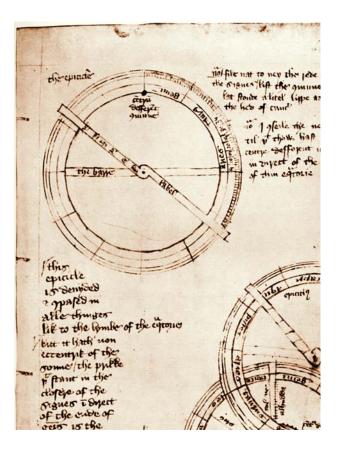



Fig. from MS Cambridge, Peterhouse 75. I:
Above: The basic disc with limb, aux, lunar and Mercury circle with bore holes, as well as the solar deferent. On the right: above, the epicycle ring with *lable* (double pointer); below: the positioning of the epicycle ring at one of the deferent points through the (commune) centrum defferent. *(*^{com}*mune) ce*^{n}*tr*^{um}

in two Latin translations, with Chaucer's work on the astrolabe could throw new light on the working method of the latter. In this connection it may be mentioned that the back of the astrolabe as depicted in Chaucer's text[5] shows a shadow scale (with *umbra recta* and *umbra versa*) which could be a successful copy of the same on the back of the extant astrolabe by Muḥammad b. aṣ-Ṣaffār (420/1029, above, p. 181). The question of the authorship of the treatise on the equatorium is even more difficult. The text is preserved only in one collective manuscript in a rough notebook that had been attributed to Chaucer (the text begins without a title). In it the auges (apogees) are defined for the year 1392. The opening formula "In the name of god pitos & m^{er}ciable" was recognised by D. J. Price as basmala ('*bismillāhi r-raḥmāni r-raḥīm*').[6] In the course of his very thorough examination he came to the conclusion "that the text of the *Equatorie* leans heavily on some text of ultimately Arabic origin, and is almost certainly a free adaptation of a Latin version."[7] Unfortunately, the Arabic source of this model has not been found so far; the model is quite independent of the other known equatoria, particularly those of the Andalusian school and of Campanus. Some features recall the *ṭabaq al-manāṭiq* of al-Kāšī (below, p. 192). As far as clarity is concerned, the Middle English text leaves nothing to be desired so that the reconstruction of the instrument is possible without any difficulties worth mentioning.

The construction is simple and meaningful, and shows thus a certain relationship to al-Ḫāzin and al-Kāšī: instead of separate discs to be constructed laboriously as in the case of Ibn as-Samḥ's or Companus's models, or the confusing number of circles stacked one into the other by az-Zarqālī, here the [**191**] radii of all deferents except the Sun and the Moon are set as equal to the radius of the disc, and the radii of the epicycles are scaled accordingly. The latter are marked together on a rotary alidade ("in maner of a lable on an astrelabie") of the movable epicycle disc. The values are trans-

[5] MS Cambridge, Rawlinson D913, v. J.D. North, *Chaucer*'s *Universe*, p. 48.

[6] D.J. Price, *The Equatorie of the Planetis*, Cambridge 1955, p. 62.

[7] Ibid., p. 164.

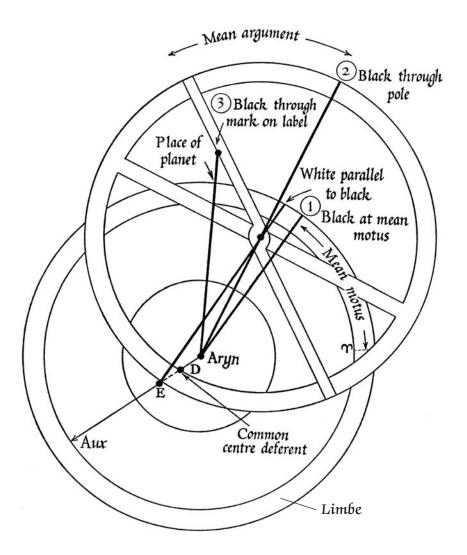
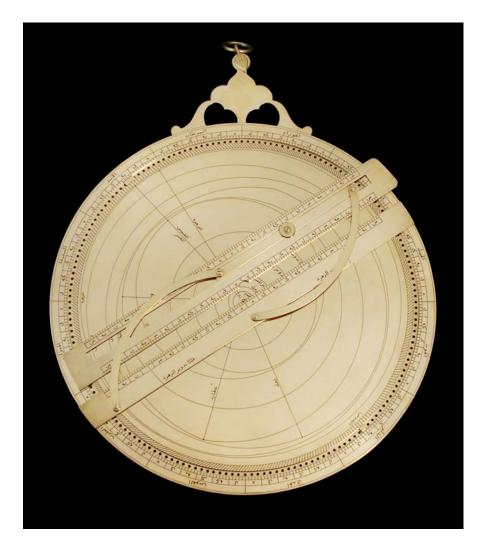
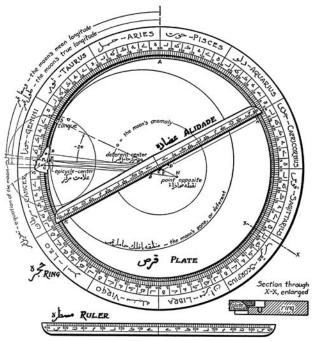
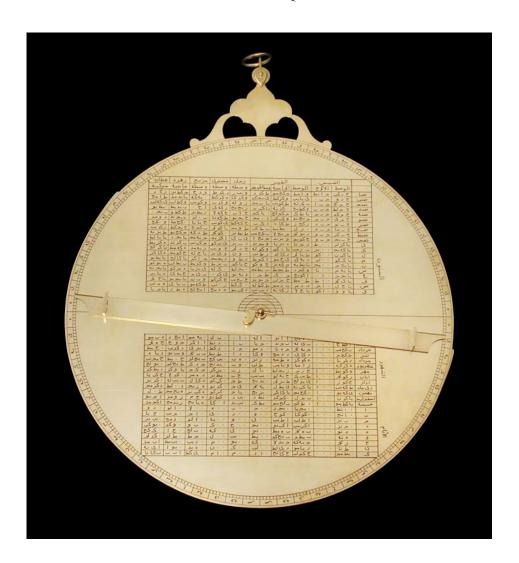



Diagram of the instrument according to Price: *Aryn* = centre of the ecliptic. D = deferent centre of the planet where the epicycle disc is inserted. E = equant. The black thread (1) is stretched from the centre of the ecliptic disc (*Aryn*) across the actual value of the mean motus, known from the table and read from the limb. The white thread is stretched from the equant parallel to thread ①, the epicycle ring is turned around E until its centre lies under the white thread. Thus the corrected position of the planet on the deferentis obtained. The epicycle disc has its own limb. On this one the mean argument, which is likewise found from the table, is set (that is, counting from thread ② which was stretched through the centre of the epicycle ring, thread (2) representing the aux of the epicycle) by turning the pointer accordingly. Then locate on the pointer the mark of the epicycle radius of the planet in question and then pull the black thread ③ through this mark to the limb of the ecliptic disc to obtain the true longitude of the planet.

ferred with two threads, so that the true longitude can be read from the common limb. Mercury is not computed with an elliptical deferent, but (by going back to the Ptolemaic model) with an additional circle, on whose circumference the deferent centre turns around the equant. This is a considerable disadvantage, since as many holes as possible have to be bored on the comparatively small circle so that the epicycle disc can be affixed at each actual position of the deferent centre. The stipulation to construct the instrument as large as possible, but at least with a diameter of 6 feet, recalls the practice, recorded since al-Ḫuǧandī (above, p. 25) in the Islamic world, to enhance the precision of measurements in this manner. However, the author (editor?) admits at a later place that his own specimen was so small that it offered space for 24 holes only (instead of the required 360) in the Mercury-circle.[8]

[8] D.J. Price, op. cit., p. 56. See also: J.D. North, *Chaucer's Universe*, Oxford 1988, pp. 156–181.

Ṭabaq al-manātiq
(Equatorium)
by al-Kāšī

Our model:
Brass, etched.
Diameter: 280 mm.
With a rotary disc and
an apparatus of parallels.
Made by M. Brunold
(Abtwil, Switzerland).
(Inventory No. A 6.05)

The great mathematician and astronomer Ġiyāṯaddīn Ǧamšīd b. Masʿūd al-Kāšī (d. 832/1429) describes in his book *Nuzhat al-ḥadāʾiq* (819/1416),[1] written in Arabic, an instrument called *ṭabaq al-manāṭiq* for the determination of the true position (longitudes and latitudes !) of the planets on the ecliptic, besides another instrument called *lauḥ al-ittiṣalāt* which serves to compute the conjunctions of the planets, and three more instruments for the computation of lunar [**193**] eclipses in advance, for the determination of parallaxes and the

Equatorium of al-Kāšī, basic construction. After E. S. Kennedy, *The Planetary Equatorium*, op. cit., p. 53, fig. 1.

[1] MS London, India Office No. 210 (v. C. Brockelmann, op. cit., suppl. vol. 2, p. 295); lithographic edition of the revised version of 829/1426: Tehran 1889 (there with appendix: Kāšī's *Miftāḥ al-ḥisāb*, pp. 250–313); anonymous Persian version, Istanbul around 900/1500; Princeton, Garrett Coll. MS 75 [44B]; facs. in: E.S. Kennedy, *The Planetary Equatorium of Jamshīd Ghiyāth al-Dīn al-Kāshī*, Princeton, New Jersey, 1960.

determination of planetary latitudes. The question that arises has not yet been pursued as to whether a connection exists between these descriptions by al-Kāšī and the three instruments of Sebastian Münster for the conjunction of the Moon and the Sun and their eclipses.[2] Thanks to the studies by E. S. Kennedy since 1947, to his facsimile edition with commentary and the English translation of the Persian version, we are well informed on both the sets of instruments.[3]

Equatorium of al-Kāšī, diagram of determining the true longitude of Mars. After E. S. Kennedy, op. cit., p. 194, fig. 9.

[2] On this and the relevant instrument by S. Münster, v. E. Poulle, *Equatories, op. cit.,* pp. 85, 299; M. Knapp, *Zu Sebastian Münsters «astronomischen Instrumenten»,* PhD thesis, Basel 1920.

[3] *Al-Kāshī's ‹Plate of Conjunctions›,* in: Isis (Cambridge, Mass.) 38/1947–48/56–59; idem, *A Fifteenth-Century Planetary Computer: al-Kāshī's ‹Ṭabaq al-Manāṭeq› 1. Motion of the Sun and Moon in Longitude,* in: Isis 41/1950/180–183; idem, *An Islamic Computer for Planetary*

The *ṭabaq al-manāṭiq* can be regarded as the climax of the development of equatoria; not only does the rationalization and clarity of its functions reach a high degree; it combines at the same time in one disc, without additional lose components, all the operations necessary for determining the longitude *and latitude* of the planets, of the Sun and the Moon at a given point of time, as also those for the computation of solar and lunar eclipses. Al-Kāšī's instrument is until now the only one known from the Islamic world that offers these additional functions. The space at the back can be used for engraving a table of the required parameters (*zīǧ*) for the computations. The whole disc is inserted in the mater so that it can be rotated for the adjustment of the auges, including the rapidly moving Moon.
Essential for the functions of the instrument is a parallel ruler which consists of an alidade and a ruler connected to each other in such a manner that they can be rotated. The latter is set—through the dot-like mark of the equant—parallel to the alidade, which lies at the centre of the disc (= the place of the observer). Where the ruler intersects the deferent circle is the actual centre of the epicycle. The radius of the epicycle is marked in the centre of the disc; there the argument is counted from the intersection of the alidade (i.e. from the mean place) and the parallel ruler is shifted until it intersects the radius of the epicycle at this point. From there the radius of the deferent is marked off on the scale of the parallel ruler and thus the true position of the planet is obtained on the epicycle (that is to say this was projected upon the deferent with the help of a parallelogram). The alidade is used to transfer this point to the limb and so to obtain the true position of the planet on the ecliptic.
Al-Kāšī constructs the Moon deferent as a resultant oval curve as az- Zarqālī had done; however, while drawing this he makes do with two strokes of the dividers, chosen to great advantage. In a supplement he describes the possibility of drawing the orbit of the Moon accordingly.

Fig. of the rotary Moon deferent
in the Persian translation, MS Princeton, f. 11 a.

In connection with the determination of the lunar latitudes, D. J. Price[5] found the trace of a certain association between al-Kāšī's *ṭabaq al-manāṭiq* and the equatorium ascribed to Chaucer (ca. 1392, above, p. 189). Another similarity in the construction by al-Kāšī with that of the planitorbium by G. Marchionis (ca.1310) was noted by E. Poulle.[5] I can explain these similarities only by assuming that al-Kāšī built upon an undocumented phase of development of the instrument in the Islamic world which also reached Europe before 710/1310. In order [**195**] to anticipate the likely objections, I may add that the preservation of such manuscripts, and particularly of instruments, remains unfortunately the exception and not the rule, and that therefore no conclusions may be drawn from their absence.
The markings for the computation of latitudes of the planets are on the back in our model and were simplified because of the smaller size of the same.

Latitudes, in: Journal of the American Oriental Society (Ann Arbor) 71/1951/13–21; idem, *A Fifteenth-Century Planetary Computer: al-Kāshī's ‹Ṭabaq al-Manāṭeq› II. Longitudes, Distances and Equations of Planets,* in: Isis 43/1952/42–50; idem, *The Planetary Equatorium of Jamshīd Ghiyāth al-Dīn al-Kāshī*, op. cit.

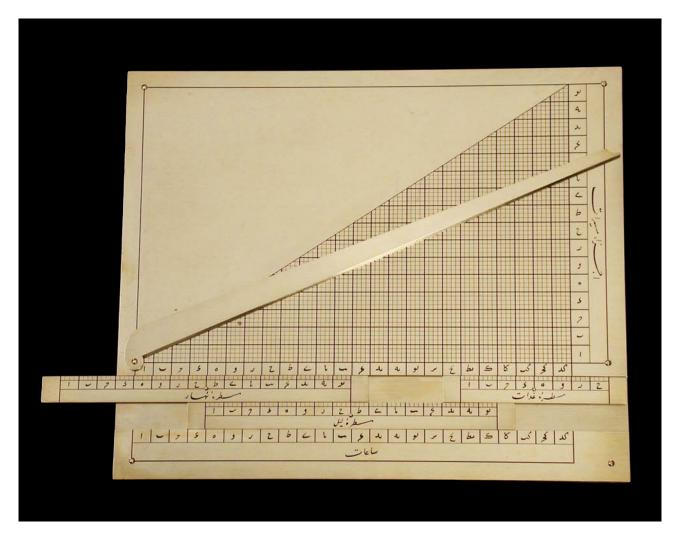
[4] v. his review of *The Planetary Equatorium of Jamshīd … al-Kāshī* by E.S. Kennedy, in: Isis 54/1963/153 f.
[5] *Équatoires et horlogerie,* op. cit., p. 192.

Table of planets (*Zīǧ*)

on the back of our model:

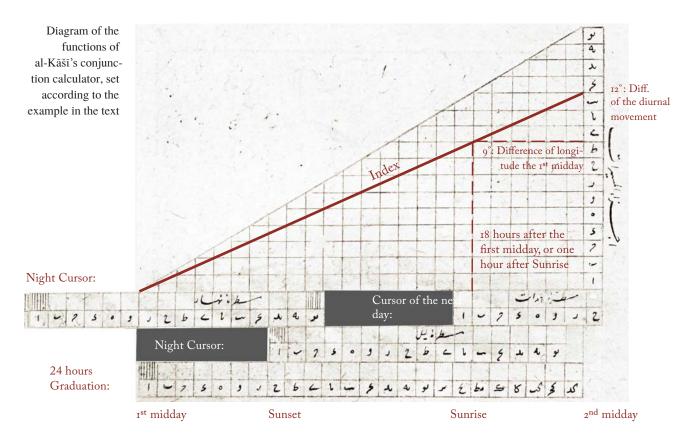
Lines, upper half:
Lines 1, 2: column-headings.
Lines 3-12: radix values at the beginning of the years *Yazdegird* 851-960. 1 year *Yazdegird* = 365.0 days. The 1st day of the year 851 *Yazdegird* is 16th November 1481 A.D.
Lines 13-22: decennials completo (completed) 10, 20, 30…100.

Lines, lower half:
Lines 1 - 12: 12 months of 30 days, completo.
Line 13: '5 days' = the rest of the year.
The values give 1 year (*Yazdegird*) *completo*.
Lines 14 - 22: days *completo*, 1, 2, 3, 4, 5, 6, 8, 10, 20 days.
The values for 30 days are in the 1st line of the month (L 1).

Columns, from right to left:
Years, months, days (1),
medius motus sun (2), *aux* Sun (3),
medius motus Moon (4), *argumentum* Moon (5), knot Moon (6),
medius motus Saturn (7), Jupiter (8), Mars (9),
argumentum Venus (10), Mercury (11).
(The places of the sexagesimal numbers correspond to: (zodiac) signs (0 – 11 s), degrees (0 - 29°), minutes (0 - 59').

Medius motus = motion of the epicycle centre on the deferent circle (seen uniformly from the equant).
Argumentum = uniform motion of the planet on the epicycle circle, measured from the connecting line from the Earth (instrument centre to the *medius motus* point on the deferent (= *centrum medium*).

Conjonction Calculator

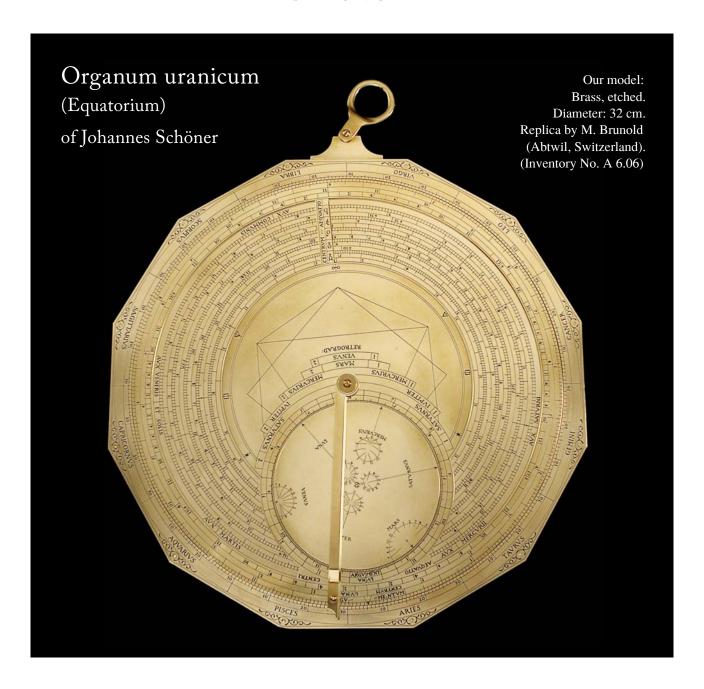
of al-Kāšī

Our model:
Brass, etched.
Length of the sides: 187 × 223 mm.
With three slides and one pointer.
Made by M. Brunold (Abtwil, Switzerland).
(Inventory No. A 6.13)

Apart from the equatorium, *ṭabaq al-manāṭiq*, described above, Ġiyāṯaddīn al-Kāšī (d. 832/1429) describes in his book *Nuzhat al-ḥadā'iq* (819/1416) [1] another instrument by the name of lauḥ al-ittiṣālāt which serves to compute the planetary conjunctions. E. S. Kennedy was the first to draw attention to this computing device in 1947.[2] Starting from the known longitude of any two planets, of the Sun or of the Moon on the ecliptic at noon time, the exact hour of an anticipated conjunction can be determined.

The instrument devised by al-Kāšī for this purpose consists of two functional units:
1.) An engraved plate with a movable pointer with which the entry of the conjunction is determined in hours from the noon of the previous day.
2.) Three horizontal slides with which the hour of conjunction is set in relation to sunrise and sunset.

[1] v. E.S. Kennedy, *The Planetary Equatorium of Jamshīd Ghiyāth al-Dīn al-Kāshī*, op. cit., pp. 68 ff., 240 ff.
[2] *Al-Kāshī's ‹Plate of Conjunctions›,* in: Isis (Cambridge, Mass.) 38/1947/56–59.

Diagram of the functions of al-Kāšī's conjunction calculator, set according to the example in the text

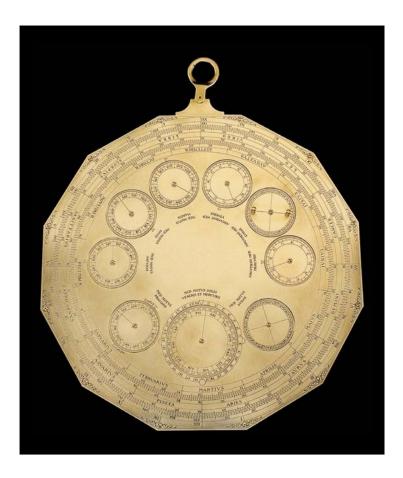
Index
12°: Diff. of the diurnal movement
9°: Difference of longitude the 1st midday
18 hours after the first midday, or one hour after Sunrise
Night Cursor:
Cursor of the next day:
Night Cursor:
24 hours Graduation:
1st midday
Sunset
Sunrise
2nd midday

An example of the use of the device: "Let the ecliptic longitudes of the two planets at noon on two consecutive days be known, where the order of the planets reverses: a conjunction takes place in these 24 hours. From the ecliptic longitudes we can derive the motions of the planets (assumed to be uniform) per 24 hours. At first the pointer is positioned at the difference of the daily motion of the two planets on the scale at the right. Example: Moon 13°, Mars 1°. The difference is 12°. Likewise on the scale at the right the longitudinal difference of the two heavenly bodies on the first noon is located and carried over horizontally towards the left up to the pointer. Example: Moon (in any arbitrary sign of the zodiac) 5°, Mars 14°, the difference is 9°. From this intersection with the pointer, go down vertically to the 24 hour scale (horizontal at the lower edge of the triangle) and find the desired time of the conjunction, in hours from the first noon, in our example 18 hours."

"With the three slides (…) the time of the conjunction can be set in relation to sunrise or sunset: Let the time between sunrise and sunset on this day be, for instance, 14 hours. Accordingly, let the length of the night be 10 hours. The upper slide on the left (the slide of the first day) is set at the 7th hour for the 1st noon, the night slide (below in the middle) is set at the 14th hour of the left slide. At the 10th hour of this night slide the slide of the next day follows (on the top at the right). On this slide of the next day we read off (in our example) the time of the conjunction at the 1st hour: one hour after sunrise."

Compared to the original, our model has been reduced in size; al-Kāšī recommends ca. 75 cm as the length of a side.

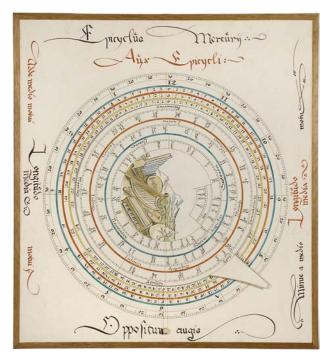
[3] M. Brunold, instruction for the use of his model.

Organum uranicum
(Equatorium)
of Johannes Schöner

Our model:
Brass, etched.
Diameter: 32 cm.
Replica by M. Brunold
(Abtwil, Switzerland).
(Inventory No. A 6.06)

The treatise on the equatorium of the German astronomer and theologian Johannes Schöner (1477-1547) enjoyed wide circulation since 1521, thanks to printing technology, as the first book on the subject. According to E. Poulle, in his publication Schöner drew from the works of Campanus of Novara (above, p. 187) and Johannes of Gmunden.[1] The originality of Schöner's presentation, besides the shifting of the eccentricity phenomenon in the depiction of the epicycle, lies in the assumption of the possibility of variations of the auges.[2] It is remarkable that this fact, which was discovered in the Arabic-Islamic area as early as in the 3rd/9th c. and could be computed with astounding precision in the 5th/11th c. (above, pp. 6, 7), was not taken note of before Schöner in Europe outside Spain, despite its presence in the Latin translation of the Toledan tables of az- Zarqālī.[3]

[1] E. Poulle, *Équatoires et horlogerie planétaire du XIII^e au XVI^e siècle*, op. cit., p. 83.

[2] Ibid., pp.85–86.

[3] v. F. Sezgin, op. cit., vol. 6, p. 43 f..

The front of our model was constructed after the paper model in Schöner's *Opera mathematica*, Nuremberg 1551, after the extant fragment of the instrument in Brussels (Musées d'art et d'histoire) and the description with diagrams by E. Poulle. M. Brunold, from whom we acquired the model, outlines its functions in the accompanying text as follows:
"The deferent radius is given concentrically, subject to the construction. The eccentricity is 'reconstructed' through 'manipulation' of the epicycle radii: On the epicycle disc of the instrument there are the six planets (Moon, Mercury, Venus, Mars, Jupiter, Saturn) not as simple dots, but in each case as a group of 12 dots. The 12 dots reflect the (seemingly) variable length of the epicycle radius and the angle correction *equatio centri*, both consequences of the eccentricity of the deferent. Depending on the position of the epicycle centre in proportion to the apsidal line (apogee = *aux*) on the eccentric deferent, one of the 12 dots or a position in between is to be chosen as the position of the planet on the epicycle. This so-called *centrum* (*verum*) is taken from the scale disc that rests under the rotary epicycle carrier. First of all, the index of the epicycle carrier is used to set the planet's mean motion on the deferent (*medius motus*) in the outer-lying zodiac, after which the *centrum* and the previously-mentioned correction *equatio* are simultaneously read off from beneath the radial "planet carrier". With the *centrum* the valid position of the planet on the epicycle disc can be found for this moment. Now the epicycle disc must be adjusted to the *argumentum* value of the planet (position on the epicycle circle), in addition to that the main index of the epicycle carrier has to be corrected by the value *equatio*, and finally the true position of the planet on the ecliptic can be read off with the pointer on the rim. By the way, the 'variable' length of the epicycle radius is not taken into account at all in Schöner's paper aequatorium (*Opera mathematica*, 1551). The surviving brass epicycle carrier in Brussels is not clear on this point, various further scales give additional information. For instance, ranges of retrogression of the planets are given in the middle of the rotary epicycle carriers, as are the astrological aspects."
A mechanical planetary calculator is on the back and represents, by means of a cogwheel mechanism, the mean motions of the planets according to the values of the Alfonsine tables which Schöner still employed, by adjusting the position of the Sun on the ecliptic according to the date and then by reading off the values at all the remaining rotary scales. This device was added by M. Brunold after his own designs "as an auxiliary means for the use of the equatorium". He relied on the fact that planetary gears had already been built, especially in planetary clocks, long before Schöner, e. g. by Lorenzo della Volpaia (1484). Since the mean motions are uniform (the anomalies are incorporated on the front, the equatorium proper), their varying rates can be transferred without any problem by means of a common gear drive.

Equatorium of S. Münster

Our model (four plates):
Water colour on cardboard in wooden frames.
Measurement each: 52 × 57 cm.
With rotary parts and threads.
Made by G. Oestmann
& F. Lühring (Bremen)
(Inventory No. A 6.07– 6.10)

The German astronomer and cosmographer Sebastian Münster (1489-1552)[1] devoted the second part of his *Organum uranicum* entirely to the equato-

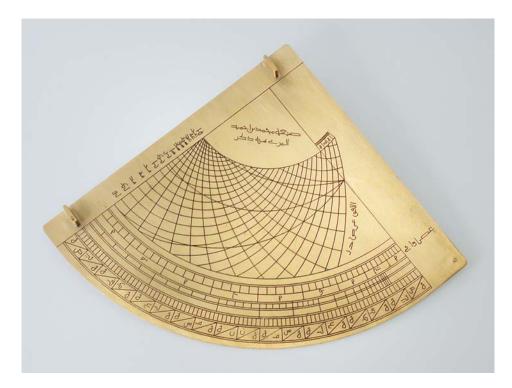
[1] v. K.H. Burmeister, *Sebastian Münster: Versuch eines biographischen Gesamtbildes,* Basel 1963; G. Kish, in: Dictionary of Scientific Biography, vol. 9, 1974, pp. 580 f.

rium. [**201**] The book is preserved in several manuscripts belonging to different versions as well as in a printed edition dating from 1536.[2] The section on the equatorium consists of the description of the 26 instruments called *Organa*: ten for determining the longitudes of the inner and outer planets, three for the longitudes of the Moon, two for determining the conjunctions of the Sun and the Moon, seven for the latitudes of the planets, and four for the computation of eclipses.[3]

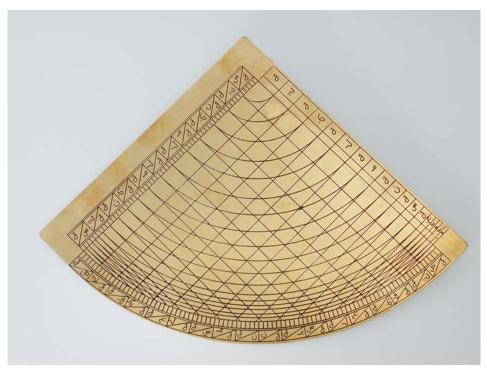
Our four chosen Organa were made by Oestmann and Lühring on the basis of the edition *Organum uranicum*, Basel 1536. These are:

Organum I, Venus epicycle: "Shown is the motion of Venus on its epicycle. By means of the instrument it can be determined which amounts must be added to (left half) or subtracted from (right half) the mean motion. *Aux Epicycli* and *Oppositum augis* indicate the point of the orbit of Venus closest to the Earth and farthest away from the Earth."

Organum II: The mean motion of Mercury. "Representation of the mean motion of Mercury. On the outermost circle is a scale of the year with the sub-divisions into the twelve months, followed by the initials of Sundays and days of the saints. In the middle area the signs of the zodiac assigned to the respective months are depicted with an ecliptic divided into 360°. The innermost circle indicates the number of minutes to be subtracted from (left half) or added to (right half) the mean motion of the planet. *Aux Epicycli* and *Oppositum augis* indicate the points of the orbit of Mercury closest to the Earth and farthest away from the Earth. To determine Mercury's position on the ecliptic, the eccentrically mounted thread is pulled tightly across the date, after which the degree of the sign and the amount to be corrected can be read off directly.

Organum III (Mercury epicycle).

Organum IV: The latitudes of Venus. "Only the Sun moves in the plane of the ecliptic, but not the Moon or other planets which can be to the south or north of the ecliptic. Ptolemy assumed that the plane of the deferent does not coincide with the plane of the ecliptic. The instrument covers the motion of the latitudes of Venus."[4]

[2] Microfiche-edition, Munich: Saur-Verlag, 1993.

[3] Cf. E. Poulle, *Équatoires…* , op. cit., pp. 299 ff.

[4] From the description de G. Oestmann & F. Lühring.

Addendum:

Another Quadrant

that bears the signature of Muḥammad b. Aḥmad al-Mizzī, 726/1326. The original is in the Museum for Islamic Art, Cairo.

Our model:
Brass, etched.
Radius 135 mm.
Front with sights.
(Inventory No. A 3.03))

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Science and Technology in Islam

III

SCIENCE AND TECHNOLOGY IN ISLAM

VOLUME III

Catalogue of the collection of instruments of the Institute for the History of Arabic and Islamic sciences

by

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in collaboration with

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Translated by

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and

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2. GEOGRAPHY • 3. NAVIGATION

4. CLOCKS

5. GEOMETRY • 6. OPTICS

2010

Institut für Geschichte der Arabisch–Islamischen Wissenschaften

an der Johann Wolfgang Goethe-Universität

Frankfurt am Main

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Chapter 2

Geography

Science does not give you anything on its own, unless you devote yourself entirely to it. But, even if you devote yourself entirely to it, it is not certain if it will give you anything.

An-Naẓẓām (died ca. 225/840)

Introduction

THE Arabs from Central Arabia, whose contacts prior to Islam to other countries and peoples had been limited to their nearest neighbours in the Arabian peninsula, Persia, Byzantium, Egypt and Ethiopia, found themselves the rulers of a large part of the old world by the first half of the first century of the Hiǧra (i.e. the migration of the Prophet Muḥammad from Mecca to Medina in the year 622). The boundaries of their rule extended up to the Pyrenees by the end of the first century of the new era, i.e. in the second decade of the 8th century A.D. In the course of this development they became familiar, as a matter of course, with the topography, customs and religions, the economy, technology and history of the conquered territories. The first literary products resulting from this bore titles like *Fatḥ* ("Conquest") or *Fatḥ* ("Conquests") of one single country or of several countries. Understandably, the earliest authors of such works were converted scholars from the Mediterranean area.

Not unconnected with the topographic descriptions in ancient Arabic poetry, even in the first half of the 2nd/8th century feverish activity in the collection of topographical data on Arabia becomes evident among philologists. The literary production emanating from this activity, which continued to increase over the centuries, finally led, in the 6th/12th century, to the compilation of a geographical encyclopedia consisting of several volumes.

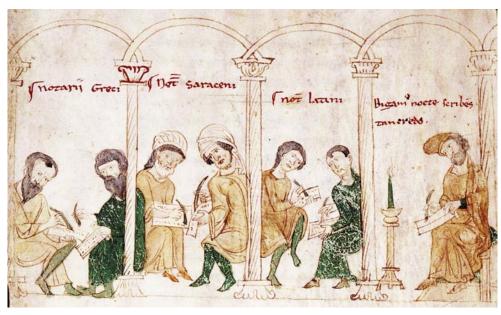
As the 2nd/8th century turned into the 3rd/9th century an independent literary genre of Arabic-Islamic geographical writings in the field of anthropogeography and historical geography emerged. This trend, independent in its origin and early development, continued for centuries in its own way, uninfluenced by the mathematical geography which had arisen in the first quarter of the 3rd/9th century, after Ptolemy's geography (ca. 180 A.D.) and the world map of Marinus (ca. 130 A.D.) had become known in the Arabic-Islamic world.

Anthropogeography, which adopted a more strictly descriptive character in the course of time, developed new characteristic traits from the beginning of the 4th/10th century, at least in connection with the cartographic representation of countries. The arrangement of the materials was now dependent on maps. These maps appear rather schematic, they acquire their meaning and their importance only through the itinerary data accompanying them. This type of cartographic representation was presumably related to a pre-Islamic geographical tradition of Sassanid Persia.[1]

The natural philosopher and geographer Abū Zaid al-Balḫī (d. 322/934) is considered the founder of this geographical school. In the course of the 4th/10th century this brannch of geographical literature flourished to a remarkable extent, thanks to his successors Aḥmad b. Muḥammad al-Ǧaihānī, Ibrāhīm b. Muḥammad al-Iṣṭaḫrī, Muḥammad b. ʿAlī Ibn Ḥauqal and Muḥammad b. Aḥmad al-Maqdisī (al-Muqaddasī). After discovering in India one of the two extant manuscripts of the book by al-Maqdisī, the youngest representative of this school, the Arabist Alois Sprenger,[2] called him the "greatest geographer who has ever lived." There has "perhaps never been a man who was so widely travelled and was such a keen observer and who at the same time processed so systematically the material he had collected." By the works of the first three authors mentioned, Abū Zaid al-Balḫī, al-Ǧaihānī and al-Iṣṭaḫrī, the geographical knowledge about Persia and Central Asia was considerably enlarged. The works of the two younger geographers, Ibn Ḥauqal and al-Maqdisī, who were from Syria and Palestine respectively, show an enormous enhancement of the geographical knowledge about Sicily, Spain, North and North-East Africa, which these geographers acquired mainly on the basis of their own observation and inquiry during repeated journeys.

[**4**] Recent research in the history of Arabic geography has recognised that Ibn Ḥauqal's outstanding

[1] v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 10, p. 130.

[2] *Die Post- und Reiserouten des Orients*, Leipzig 1864 (reprint Islamic Geography, vol. 112), preface, p. 18; F. Sezgin, op. cit., vol. 10, p. 346.

characteristic was that in his entire book a close connection, peculiar to him, can be seen between the spatial context and the passage of time.[3] The material that he presents has a special value not only from the viewpoint of the history of geography, but also for the history of culture, particularly because he clearly goes beyond his predecessors and even describes for us countries which he cannot have been in a position to know personally. Although it was Ibn Ḥauqal's aim to present the geography of the Islamic world, he furnishes us with quite a lot of information about non-Islamic countries as well.

The importance for the history of geography of the most recent representative of this school, al-Maqdisī, whom—as was already mentioned—A. Sprenger in 1864 called the "greatest geographer ever", has been brought to light in exemplary fashion by contemporary research, particularly thanks to the indefatigable efforts of André Miquel.[4] Miquel takes the view that al-Maqdisī's "meticulous and thorough expositions created a new anthropogeography—albeit one which was not uninfluenced by the traditional connection, rooted in Arab geography, between people, places and climates—which was innovative in the vivid manner in which it elucidated its content. Even in his foreword, Miquel continues, al-Maqdisī stands out in the programme of his intended objectives, which can rightly be regarded as the basis for a new, comprehensive anthropogeography, as is confirmed by the way that he implements this in his work."

This universal application of anthropogeography is revealed in the following centuries more in the geographical writings in Persian than in Arabic. Yet the precise and detailed depiction of civilised life and of nature, which had developed in the works of the school of anthropogeography, retained its validity over the centuries in countless books on urban and regional geography. It is to be regretted that the works of these geographers remained completely unknown to Europeans in the Middle Ages. Of course, the Iberian peninsula and Sicily must be excluded from this assessment. With this proviso, we must discuss the singular appearance of the world map completed in 549/1154 and the voluminous geographical book by Abū ʿAbdallāh Muḥammad b. Muḥammad aš-Šarīf al-Idrīsī.

Chancellery at the Norman court in Sicily, filled with Greek, Arabic and Latin scribes (Petrus de Ebulo, *Liber ad honorem Augusti sive de rebus Siculis. Codex 120 II der Burgerbibliothek Bern*, ed. Theo Kölzer and Marlis Stähli, Sigmaringen 1994, p. 59).

[3] v. André Miquel, *La géographie humaine du monde musulman jusqu'au milieu du 11ᵉ siècle*, vol. 1, Paris 1967, p. 309.
[4] Ibid., vol. 1, pp. 324–328.

[**5**] According to Arabic sources, it was "the Norman king Roger II, known for his great sympathy for natural sciences and philosophy, who had invited aš-Šarīf al-Idrīsī, the author of *Nuzhat al-muštāq*, from North Africa" and commissioned him to compile a world map. Al-Idrīsī demanded the metal necessary for it and the king put sufficient silver at his disposal.[5]

Al-Idrīsī's long stay in Sicily, probably lasting from 1138 to 1161, i.e. beyond the year of the death of Roger II, brought forth at least four results: 1. a circular, engraved world map in silver, 2. the world map divided into 70 sections, 3. the *Kitāb Nuzhat al-muštāq fī ḫtirāq al-āfā*q and 4. the *Kitāb Uns al-muhağ wa-rauḍ al-farağ*. In 1160, six years after Roger's death, during an insurrection under his successor William I, the circular silver plate, the Tabula Rogeriana, was broken into pieces by insurgents, who divided the pieces amongst themselves.[6]

As al-Idrīsī himself[7] states, the map was circular. It is preserved in several manuscripts, although in a rather distorted form.

The importance of his world map, the regional maps and the book of geography is assessed variously in modern studies. In particular, only a few of those who do research on Idrīsī have taken any cognizance at all of his circular world map and included it in their assessment. As a rule, they direct their attention to the rectangular world map, reconstructed by Konrad Miller in 1928 on the basis of the 70 regional maps, in which the northern part of the inhabited Earth is as long as the zone of the Equator. We cannot be grateful enough to Miller for his laudable efforts in editing the maps and translating the relevant passages from al-Idrīsī's book. However, he was unfortunately led to the erroneous view that the map created by al-Idrīsī had not been circular but rectangular. Accordingly he declared that the statement in the manuscript of al-Idrīsī's book that the map had had the form of a circle (*dā'ira*)[8] was a copyist's error.[9] I believe that the conditions (to which the preliminary work by Miller also belongs) today are more favourable for making the attempt—on the basis of the regional maps and al-Idrīsī's book, and by taking into account the extant, much distorted circular maps—to reconstruct a world map approximating to the original, perhaps also on a silver plate.

The questions about the sources of the Idrīsī maps and their position in the history of cartography receive widely divergent answers in present-day studies. In the narrow confines of this introduction I can report in brief only about certain conclusions which I reached during my work on the *Mathematical Geography and Cartography in Islam and their Continuation in the Occident* (see below).

After the discovery of the circular world map of the Ma'mūn geographers (ca. 215/830 A.D.), it is easy to show that al-Idrīsī used this map substantially as the basis for his own map made in Palermo. However, he replaced the graticule of his model with seven lines of climates, drawn erroneously as equidistant. Among the improvements noticeable in the Idrīsī map in comparison to its predecessor are a substantially improved shape of the Mediterranean and a better topography of Europe. What is even more important, it seems to me, is that al-Idrīsī establishes a new image and a new topography for many parts of Asia. Only after the discovery of the world map of the Ma'mūn geographers and the confirmation that this was al-Idrīsī's main source, can this new element be recognised. First of all, the Ma'mūn geographers fundamentally corrected the outermost north-east of the oikoumene vis-à-vis the Ptolemaic idea of a contiguous landmass through their notion of the limitation of this region by a navigable encompassing ocean. Then, in al-Idrīsī's world map the north-eastern part of Asia is shown substantially smaller and rounded, and is given the shape of a saddle.

The striking [**6**] difference in the Idrīsī map is, however, not limited to the configuration, but gains special importance through the expansion of the hydrographic content and a different representation of the orographic features. In this map a number of inland lakes and rivers are to be found which are absent in the Ma'mūn map. Only a few years ago the question was posed: what is the origin of the changed configuration of North and North East Asia and the reconfiguration of Central Asia? Most

[5] al-Ḫalīl b. Aibak aṣ-Ṣafadī, *al-Wāfī bi-l-wafayāt*, vol. 14, Wiesbaden 1982, pp. 105-106.

[6] v. K. Miller, *Mappae Arabicae*, vol. 1, Stuttgart 1926 (reprint. Islamic Geography, vol. 260), p. 39.

[7] *Nuzhat al-muštāq*, op. cit., p. 6.

[8] Ibid., p. 6.

[9] K. Miller, op. cit., p. 38

probably all this goes back to a Kīmāk-Turkic source from the 5th/11th or the 6th/12th century to which no attention has been paid so far, which al-Idrīsī mentions in the foreword of his book.[10]
We can follow the deep influences which the Idrīsī map left on maps originating in Europe from the turn of the 7th/13th to the 8th/14th century. As far as the text of the book is concerned, which contains more valuable information on European countries than any other Arabic geographical work, it does not seem to have met with any real interest in Europe until the end of the 10th/16th century.
After these brief expositions about al-Idrīsī's work, we may also mention the geography based on travellers' reports which was carried on in the Arabic-Islamic world. The early brisk trade and commerce of the Islamic world with China by sea, existing since the 1st/7th century, is a well-known historical fact.[11] Contacts with India and the interest in her culture and science were so well developed that the Abbasid Caliph al-Manṣūr (ruled 136/754-158/775) invited some Indian scholars to Baghdad and caused the most important astronomical book of the Indians to be translated into Arabic around 154/770.[12] It is also one of the important events in the history of culture that the Abbasid statesman Yaḥyā b. Ḫālid al-Barmakī (d. 190/805), who was very interested in science and culture and invited Indian physicians to Baghdad, sent a scholar to India so that he would write a book on the religion of the Indians. Some fragments from this book are fortunately preserved.[13] Therefore we should not be surprised when we hear about travelogues of Arab-Islamic scholars from this early period. The earliest Arab traveller known to us who offers us the description of a journey to China by the land route, was called Tamīm b. Baḥr al-Muṭṭauwiʿī. The extant parts of his report make it possible to place the date of the journey between 206/821 and 209/824.[14]
From the first half of the 3rd/9th century we know of some reports of Arab travellers to western Central Asia, India and Byzantium which we can leave aside here. Arabists have noted with special interest the report of the journey to Constantinople and Rome by Hārūn b. Yaḥyā (ca. 300/912),[15] as well as the reports by Ibrāhīm b. Yaʿqūb (ca. 350/961) on the Slavs[16] and by Aḥmad Ibn Faḍlān (1st half of the 4th/10th c.) on the Bulgarians to the north of the Caspian Sea and the Russians.[17] Here we are also given information on the history, geography and ethnicity of the Oġuz Turks, the Normans and on "Wisū", lying far in the north, as well as the northern Polar Sea. In two reports by Abū Dulaf[18] (1st half of the 4th/10th c.), a journey through Mā warāʾ an-nahr (Transoxania) and Central Asia and another through Persia and the Caucasus are described.
Leaving aside other travellers of the 4th/10th and the 5th/11th centuries, I mention ʿAlī b. al-Ḥusain al-Masʿūdī (345/956)[19] and Muḥammad b. Aḥmad al-Bīrūnī (d. 440/1048).[20]
[7] The former did not leave us a travelogue in the strict sense of the word, but numerous works of philosophical, historical and geographical content, written during his ca. 30 years of wanderings, during which he wished to discover the world on the basis of his own experiences. We do not know how many countries he visited, since many of his works are lost. It appears certain that he went from his hometown Baghdad to Persia, India, Zanzibar, Madagascar, Arabia and North Africa, but it is not known how often he visited individual countries.
What motivated us to mention al-Bīrūnī in the context of travel literature is the book on India which he wrote—on the basis of his many journeys in the region and his numerous contacts with the inhabitants—about the religions, sciences and customs of the country with an objectivity and a love of truth considered exemplary for all times. This great universal scholar says in his introduction: "This book is not a polemic, but merely a simple report of facts. I shall develop the theories of the Hindus as they are and shall mention, in connection with this, similar theories of the Greeks in order to point out the relationship between the two." On this, the transla-

[10] v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 10, pp. 348–350.
[11] v. ibid., vol. 10, p. 546.
[12] v. ibid., vol. 6, pp. 116–118.
[13] Ibn an-Nadīm, *Kitāb al-Fihrist*, ed. G. Flügel, vol. 1, Leipzig 1872, pp. 345 ff.
[14] Vladimir Minorsky, *Tamīm b. Baḥr's Journey to the Uyghurs*, in: Bulletin of the School of Oriental and African Studies (London) 12/1947–48/275–305.
[15] Studies on this are collected in Islamic Geography, vol. 166, Frankfurt 1994.
[16] Studies on this in Islamic Geography, vol. 159, Frankfurt 1994.
[17] Studies on this in Islamic Geography, vol. 169, Frankfurt 1994.
[18] Ibid., vol. 169.
[19] v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 1, pp. 332-336; vol. 6, pp. 198–203; vol. 7, pp. 276–277.
[20] ibid. vol. 5, pp. 375–383; vol. 6, pp. 261–276; vol. 7, pp. 188–192, 288–292.

tor of this passage, Max Krause, remarks:[21] "This principle is followed conscientiously, the teachings of the Indians, as far as they were known to the author through oral tradition or from literature, are reproduced with utmost meticulous care. He does not hesitate either to state that he could not find any or any definite information on some point or the other, and to point out the differences between the various reports. His own view on these matters is expressed, if at all, at the end of the individual sections. His book is not meant to provide material for those who want to fight against the Indians, but for those who want to get to know and appreciate them and their views."

In order that the exposition about travel geography does not become too long in this brief overview of anthropogeography, I shall restrict myself at this point to the name of Muḥammad b. Aḥmad Ibn Ǧubair (d. 614/1217)[22] from Valencia, who undertook three journeys from his home from 578/1183 onwards, the first of which took him as far as Arabia. The description of his experiences and observations, which he apparently put into writing almost daily, is one of the most interesting documents in Arabic geography. His observations on art, culture, and architecture, on administration and ethnology are of great value for the history of anthropogeography. Ibn Ǧubair's travelogue becomes an indispensable source, especially for the history of Sicily and its cultural history under the Norman king William II.

[**8**] I shall pass over the other names and mention Abu l-ʿAbbās an-Nabātī from Seville[23] (d. 637/1240), in whose "Journey to the Orient" (*ar-Riḥla al-mašriqīya*), the geography of plants, which had been the subject of study since Abū Ḥanīfa ad-Dīnawarī (d. ca. 282/895),[24] reached a remarkable standard.

To conclude this overview of geographies based on travellers' reports, we should mention Muḥammad b. Ibrāhīm Ibn Baṭṭūṭa from Tangiers (d. 770/1369). At the age of 22, this Moroccan left the city of his birth in 725/1325 and turned towards the east, urged on by an insatiable wanderlust and an irresistible desire to acquaint himself with the unknown. After staying in North Africa, Egypt, Arabia, East Africa as far as Mozambique, Anatolia, Byzantium, southern Russia up to the 55th latitude at the confluence of the Kama with the Volga, Central Asia, India, the Malay peninsula and China, with intermediate places which he visited repeatedly, his first journey came to an end after almost 24 years. With a second journey to Andalusia and a third to Africa, he spent, all in all, 27 years in foreign countries. According to R. Hennig,[25] Ibn Baṭṭūṭa "can be considered altogether the greatest world traveller whom Antiquity and the Middle Ages ever brought forth." He was "a true explorer, who absorbed with open eyes all impressions, assimilated them and

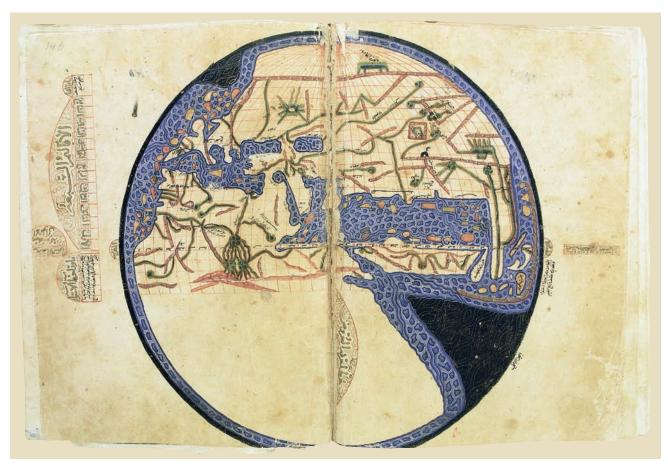
Arab physicians and astronomers at the sickbed of William II in Palermo (Petrus de Ebulo, *Liber ad honorem Augusti sive de rebus Siculis*, op. cit., p. 43).

[21] *Al-Biruni. Ein iranischer Forscher des Mittelalters*, in: Der Islam (Berlin) 26/1942/1–15, esp. pp. 13–14 (reprint in: Islamic Mathematics and Astronomy, vol. 36, Frankfurt 1998, pp. 1–15, esp. pp. 13–14).

[22] For studies on him see Islamic Geography, vols. 172 and 173, Frankfurt 1994.

[23] v. I. Kračkovskij, *Istoria arabskoi geografičeskoi literaturi*, Moscow 1957, p. 345.

[24] v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 4, pp. 338–343.

[25] *Terrae incognitae*, vol. 3, Leiden 1953, p. 213.

who, fortunately, left behind a very detailed, indeed one can say a voluminous travelogue, a source of geographical information of a high order." Ibn Baṭṭūṭa had "probably seen three times as many foreign countries as Marco Polo did."[26]

Arabist research in anthropogeography and its subsidiary branches, historical geography, urban and regional geography, and travelogue geography, began two hundred years ago. Arabists have been able to bring to light the importance of the achievements of the Arabic-Islamic world in this field considerably better than in other fields. Most of their studies in this regard, translations and text editions were collected and published in 278 volumes by the Institute for the History of the Arabic-Islamic Science at the University of Frankfurt in its series of publications Islamic Geography. On the whole, it is noticeable that mathematical geography has not been accorded enough attention by researchers and that the great achievement of the Arabic-Islamic world in the field of cartography, developed on the basis of mathematics and astronomy, has remained largely unknown since the rquired maps were not yet available to the scholars. Through fortunate circumstances like the discovery of the world map and the regional maps of the Maʾmūn geographers, the author of this overview was led to attempt to fill this lacuna. The results of his work, which took almost 15 years, have been made available for the discussion of the scholarly world in three volumes with the title *Mathematische Geographie und Kartographie im Islam und ihr Fortleben im Abendland* (Frankfurt 2000)[27]. An overview of some of the results of the book for a more general reader appeared in the journal Forschung Frankfurt (No. 4, 2000), which is hereby made available to the user of the catalogue:

[26] ibid, p. 213; for studies on Ibn Baṭṭūṭa, v. Islamic Geography, vols. 175-183, Frankfurt 1994.

[27] English version: *Mathematical Geography and Cartography in Islam and their Continuation in the Occident* – I-II: *Historical Presentation*, Parts 1-2, Institute for the History of Arabic-Islamic Science, Frankfurt 2005-2007.

Fig. 1: The world map commissioned by Caliph al-Ma'mūn in the first third of the 9th century, in a copy dating back to 1340. Its outstanding feature—apart from its globular projection—is a continuous ocean surrounding the landmasses, showing Africa as a continent which can be circumnavigated and the Indian Ocean—in contrast to its Ptolemaic representation as an inland sea—as an open sea.

Arab Origin of European Maps

The cartographic image of the Earth's surface which we inherited in the 20th century has doubtless attained a high degree of precision. However, its accuracy has yet to be verified. Only now is it becoming possible, thanks to advances made in sciences associated with today's image of the world, viz. the observations and measurements resulting from space technology, to complete this unfinished business. Even if corrections to this image need to be undertaken, they will not impair the general validity of the image, which is the joint inheritance of all humanity. Our predecessors did not yet have the advantage of this experience in the second half of the 19th century.

The work of the fledgling discipline of the historiography of cartography, which involves appropriately describing, as far as possible, the individual stages of development and the contributions made by different cultures, is immensely difficult. No doubt it will never be revealed to us when and where the first attempt was made to represent pictorially part of the Earth's surface by human hands. Fortunately, attempts by the Babylonians and Ancient Egyptians to sketch out their perception of the inhabited world are known. We also know that as long ago as 530 B.C. the Carthaginian Hanno was able to sail from his native city and penetrate the interior of the Gulf of Guinea, approximately down to the Equator. Herodotos tells us of a Phoenician circumnavigation of Africa commissioned by Pharaoh Necho (ca. 596-584 B.C.). This Pharaoh is alleged to have ordered his sailors to sail southwards from the Red Sea along the coasts until they [**10**] passed through the pillars of Hercules and returned via the Mediterranean to Egypt. They are said to have completed the task within three years.

The Beginning of Mathematical Geography in Greece

The Greeks created the basis for mathematical documentation of the known surface of the Earth by postulating that the Earth was a sphere in the 5th and 4th centuries B.C., by making the first attempt to measure the Earth in the 3rd century B.C. and by transferring the Babylonian division of the firmament into 360° in the great circle onto the Earth. They also contributed both the idea of longitudes in the sense of the time difference between places by simultaneously observing lunar eclipses and the proposition of the identity of the geographical latitude of a place and the altitude of the pole, which is fundamental to determining locations.
Hipparchus, one of the greatest of Greek astronomers, found that it was not yet feasible in the third quarter of the 2nd century B.C. to draw a map which was substantiated by mathematical and astronomical data. He regarded the cartographic achievements of geographic science to date as premature and unsuccessful, counselling patience and the collection of adequately precise coordinates. The compilation of a map was, he averred, a task for the future, which could not be implemented until a large number of scholars in various countries had completed the spadework required. There is no doubt that the Greeks had at their disposal one difference in longitude: it had been calculated in 331 B.C. by the method of observing lunar eclipses between Carthage and Arbela, and was approximately 11° too large. Latitudes calculated over the course of time, measurements of distances obtained on ships' voyages or by the Roman army, and data gained by other means in route books resulted in the first half of the 2nd century A.D. in a map of the known world using an orthogonal projection. Its creator was Marinus of Tyre. His younger contemporary Ptolemy leads us to traces of Marinus's long lost map. To all appearances, this map and its accompanying text was the sole basis for Ptolemy's geography. As we have learnt, Marinus had based his map of the known world on a graticule whose longitude was 225°, i.e. ca. 80° to 90° too large. His successor Ptolemy felt moved to compile a book using the data and information about degrees which he obtained from this map of the known world (possibly also from the regional maps enclosed) and the accompanying text. This book was to serve later generations as a basis for compiling new editions of the map. While working on [**11**] his predecessor's data he came to the conclusion that the data on routes, especially the east-west ones in terms of longitudes, were excessively large. He therefore systematically reduced in proportion the size of the parts involving Asia. While retaining the longitude of the

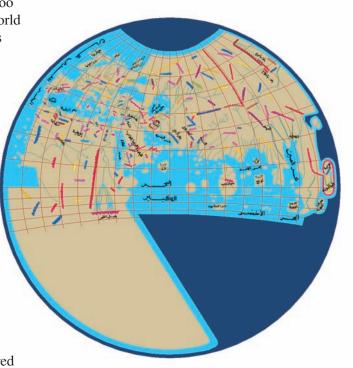



Fig. 2: World map from Ptolemy's Geography in a manuscript from the first half of the 14th century, reconstructed by the Byzantine scholar Maximos Planudes. In contrast to the Ma'mūn geography (*figs. 1 & 3*), the Indian Ocean and the North Atlantic are still shown here as inland seas.

grand axis of the Mediterranean at 63° (ca. 21° too large), he reduced the longitude of the known world to 180° (still ca. 40° too much). Ptolemy appears not to have enclosed a map in his book. It is astonishing that his text conveys the picture of a continuous landmass, in which the North Atlantic and the Indian Ocean are shown as inland seas.

The Oldest Known World Map with a Globular Projection

Marinus's cartographic achievement and Ptolemy's Geography reached the Arab-Islamic world in the early 9th century, at a time when this extended from the Atlantic across to India and its inhabitants were in the process of acquiring the learning of other peoples, being on the threshold of their creative period. Caliph al-Maʾmūn, who sponsored all the areas of learning of his time, commissioned a large group of scholars to create a new "Geography" and a world map. It goes without saying that in carrying out this task the scholars mainly had to follow in the footsteps of the achievements of their Greek mentors.
Fortunately, some parts of the atlas and its accompanying geographical work, which were the result of this assignment, still survive. From the point of view of the history of mathematical geography and cartography it is of outstanding importance that the world map of the Maʾmūn geographers re-emerged during the 1980s in a copy from the year 1340. It is without doubt a copy of what was once a magnificent original, albeit rather distorted as a result of repeated copying (*fig.* 1). However, thanks to a surviving table of coordinates, which had been simultaneously excerpted from the original map, it proves to be a unique cartographic monument: it uses a globular projection. It shows a west-east extension of the inhabited world which is reduced by 15°- 20°, with at the same time a longitudinal axis of the Mediterranean reduced by 10°. Furthermore, it is very significant that the Marinus-Ptolemaic notion of a continuous landmass has been replaced by a new version. This involves the inhabited world being surrounded by an "Encompassing Ocean", which in turn is surrounded by an "Ocean of Darkness". The Atlantic and the Indian Ocean are no longer inland seas, forming part of the Encompassing Ocean (*fig.* 3).

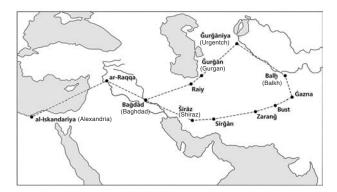



Fig. 3: Reconstruction of the world map of Caliph al-Maʾmūn according to the data of the surviving book of coordinates of one of the Maʾmūn geographers. A comparison with the surviving map (*fig. 1*) shows that they are basically identical and that in addition, in several details, the reconstruction conveys a more precise idea of the lost original than the surviving version, which has been modified by repeated copying.

The attempts by the Greeks to achieve a precise cartographic representation of the Earth's surface and [**12**] the mathematical-astronomical methods used to this end, which had culminated in the work of Marinus and Ptolemy (*fig.* 2), and had at the same time reached the limits of their potential for development in their own culture, entered into a new evolutionary phase due to the work of Caliph al-Maʾmūn's geographers. We are experiencing the most recent period of this phase in our own times. In my recently published book *Mathematische Geographie und Kartographie im Islam und ihr Fortleben im Abendland* (vols. X-XII of my *Geschichte des arabischen Schrifttums*)[1] I have attempted to convey to a specialist readership the phenomena of

[1] English version: *Mathematical Geography and Cartography in Islam and their Continuation in the Occident – I-II: Historical Presentation*, Parts 1-2, Institute for the History of Arabic-Islamic Science, Frankfurt 2005-2007.

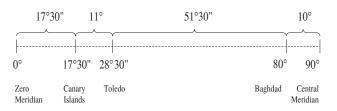



Fig. 4: Schematic diagram of the routes measured by al-Bīrūnī in the first quarter of the 11th century and of latitudes he ascertained astronomically for calculating the longitudes of ca. 60 places between Baghdad and Ghazna.

an uninterrupted continuous development which were revealed to me. In what follows I would like to point out several aspects of this development process which seem important to me.

Expansion of Mathematical Geography into an Independent Discipline

The geographic positioning of places which was carried on intensively and with scholarly meticulousness in the Islamic world led, in the first quarter of the 11th century, to the emergence of mathematical geography as an independent discipline. The credit is due to al-Bīrūnī, one of the most important scholars of the Arab-Islamic world. He made the attempt, unique in the history of geography, to determine the longitudes and latitudes of major places located between Ghazna (in modern Afghanistan) and Baghdad (within a radius of approximately twice 2000 kms) on the basis of astronomical observation, the measurement of routes and the use of the rules of spherical trigonometry (*fig.* 4). The errors he made in the data of longitudes of about 60 places, when compared with modern values, only amount to between 6 and 40 minutes. His data were used as the basis for the determination of coordinates, which was continued unbroken for centuries in the eastern part of the Islamic world. The additional corrections to longitudes made in the part of the Islamic world west of Baghdad resulted as early as the first half of the 11th century in reducing the east-west axis of the Mediterranean to 44° - 45° (now 42°), and as a consequence of this to a relocation of the zero meridian into the Atlantic at 17°30' west of the Canary Islands, i.e. 28°30' west of Toledo.

The First Arab Maps in Europe

There are several Arab and European maps surviving which reveal the after-effects of the Ma’mūn geography. They include the world map and regional maps of the geographer al-Idrīsī (*fig.* 5) of 1154. The maps and the geographical work by this aristocrat from Ceuta, which he compiled in Sicily at the behest of the Norman king Roger II, show a high degree of similarity to the maps of the Ma’mūn geographers, although they also involve a not inconsiderable expansion and improvement to the Mediterranean and particularly to North-East, Eastern and Central Asia. One fact which has not been given its due attention in the history of cartography is that around 1265 in South-West Europe a world map emerged which shows striking divergences from contemporary European maps, revealing an astonishing similarity to the world maps of the Ma’mūn geographers and al-Idrīsī (*fig.* 6).

Fig. 5: World map of al-Idrīsī (compiled 1154), copy from 1500. The map is largely based on the Ma'mūn map (*figs. 1 & 2*). What is striking is the substantially improved representation of North and North-East Asia, which for centuries had a significant influence on later European maps of Asia.

Fig. 6: The oldest known European imitation of the world maps of the Ma'mūn geographers (*figs. 1 & 2*) and al-Idrīsī (*fig. 5*), preserved in the encyclopedic work *Tresor* (ca. 1265) by Brunetto Latini, where there is no connection at all between the text of the book and the map, the latter being an exotic insertion in the book.

Fig. 7: World map by Marino Sanuto–Petrus Vesconte (ca. 1320), an imitation of the world map of al-Idrīsī (*fig. 5*), as is clearly evident from the basic outlines and the details.

About a third of a century later, as the 13th century turned into the 14th, a series of maps emerged which give an almost correct representation of the Mediterranean and the Black Sea. Historians of cartography have called them, not quite accurately, portolan maps. The question of their origin has been discussed for about 150 years. According to some scholars they are said to have emerged suddenly; their originators, they claim, were European navigators. Some other historians of cartography associate them with various older cultures. Basing his assertions on the rudimentary knowledge of Arab geography of the time, Joachim Lelewel (ca. 1850), the first or one of the first scholars to discuss the origin of these maps, was convinced that the maps were derivatives of the map and the geographical work of al-Idrīsī (*fig.* 7).

Emergence of a New Type of Map in Europe

A thorough study of this question in the light of the history of mathematical geography and cartography of the Arab-Islamic world shows that not only these so-called portolan maps but also the European world and regional maps which began to appear shortly afterwards have direct or indirect links with maps from the Arab-Islamic world down to the 18th century. Research in the history of cartography dealing with the origin of both the so-called portolan maps and the representations of Asia and Africa on world and regional maps in the course of the subsequent period has always treated these questions in isolation, as separate issues, and in almost total ignorance of the mathematical geography and cartography of the Arab-Islamic world. Whereas the issue of the origin of the portolan maps is regarded as an unsolved mystery, the important new parts of the inhabited world and their topographic elements, which crop up for the first time on world and regional maps, are explained as the achievements of European mapmakers, which were made possible by the explorations of travellers and their travel reports. According to this view, a mapmaker located in, say, Venice, Genoa or Majorca is supposed to have been capable [**15**] of drawing a near-perfect

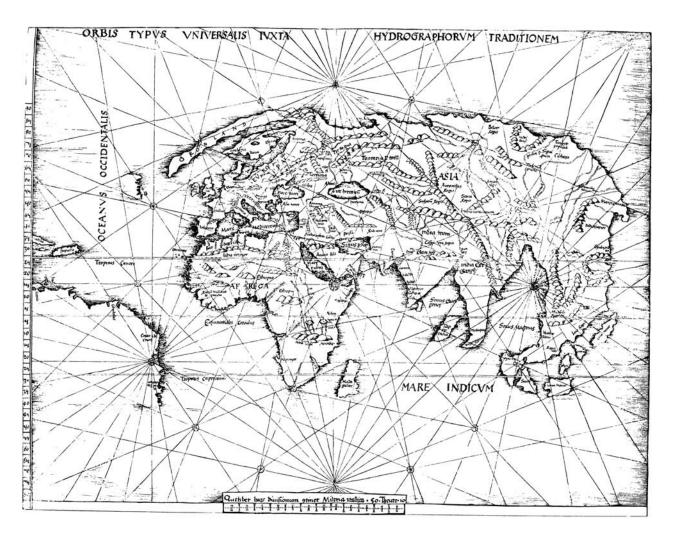



Fig. 8: Pseudo-Ptolemaic world map from Ptolemy's Geography, Strasbourg 1513. Africa appears in near-perfect shape, while South-East Asia is represented in a very old-fashioned way reminiscent of the Ma'mūn geography (*figs. 1 & 2*). Neither can be reconciled with the Ptolemaic image of the world.

outline of the Caspian Sea, the Indian subcontinent or even of a relatively small lake such as Lake Urmia, simply on the basis of travellers' reports or explorations. Does this not mean that we are ascribing superhuman ability to a mapmaker, are we not expecting from him a feat which he could not possibly achieve? Would it not be more acceptable and logical to entertain the possibility that this or that mapmaker might perhaps have got hold of a map which had been produced locally and which could only have been made in the course of centuries, as the result of the work of several generations ?

Influence of Ptolemaic Geography on Cartography in Europe

In the last quarter of the 15th century a new tendency arose in European cartography, as a result of the printing of the Latin translation of Ptolemy's Geography. Many maps bearing Ptolemy's Latinised name which were not completely identical with the content of his Geography (*fig.* 8) managed to come into circulation. These and other world maps based on them, which emerged over a period of about 50 years, were provided with graticules on which the longitude of the Mediterranean, for example, was given as 63°, with the southern tip of the Indian subcontinent being 125°. Whereas this "Ptolemaic" graticule was able to survive on some world maps down to the mid-16th century and for a few years after, from about 1510 it was superseded on most world maps in the dimensions mentioned by the graticule [**16**] of the Ma'mūn world map, where the longitude of the Mediterranean was 52° or 53° and the longitude of the southern tip of India 115°.

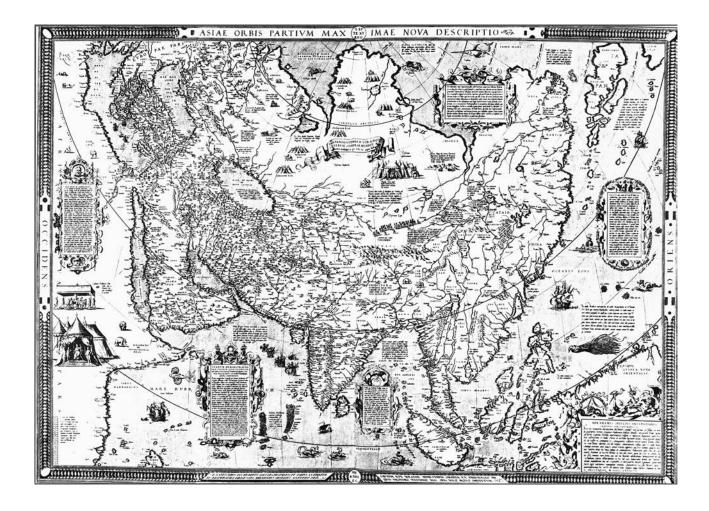



Fig. 9: Map of Asia by Abraham Ortelius (Antwerp 1567), published as a new edition of the Gastaldi map. In the bottom right-hand corner Ortelius remarks that Gastaldi compiled this map in the Arab tradition.

Break With Ptolemaic Geography

The three-part map of Asia and the new world map published in 1560 and 1561 by Giacomo Gastaldi had a revolutionary effect. This Italian engineer and cartographer, who had dedicated himself for about 30 years to drawing "Ptolemaic" maps, now published maps of a completely different type, with a different graticule, different outlines, a new topography and toponymy. How and why did this happen? He gave no explanation for it himself. Several years later his two colleagues, Abraham Ortelius (*fig.* 9) and Gerard Mercator, the most famous cartographers of their times, published their own version of Gastaldi's map of Asia, with some alterations or additions. What criteria did they have to assume that this map was correct or was more correct than others? Where did Gastaldi's coordinates come from? Ortelius thought that he had got to the bottom of the secret. In the lower right-hand corner of his map he noted down: "We hereby offer our esteemed readers a new representation of Asia, which Jacobus Gastaldus, a man who has rendered sterling service to geography, compiled according to the tradition of the Arab cosmographer Abu l-Fidāʾ." Ortelius is referring here to the book of comparative tables of coordinates by the Arab geographer Abu l-Fidāʾ (d. 1331), a manuscript of which had been

brought back from Istanbul to France by the French Orientalist Guillaume Postel in 1524. Although the book contained coordinates [**17**] which in the Islamic world were long since outdated and had been replaced by more correct ones, in Europe the author was celebrated in the second half of the 16th century as a new Ptolemy, familiarity with his book was hailed as "venit divinamente in luce …" or "coming divinely to light in our time".
In reality neither the coordinates of Abu l-Fidā''s book would have sufficed to draw the configuration of the Gastaldi map, nor did the map agree with the book's data. My view is that Gastaldi must have used a general map or several regional maps from the Arab-Islamic world as his sources. How expertly he used these is a separate question. Not only does the incorrect explanation which Ortelius gave for the origin of the Gastaldi map permit us to conclude that those geographers in Europe who were the leading exponents of their subject in their day were not aware of how their source maps had originated and where they came from, apart from the fact that they did not know, or rather could not have known which of the source maps known to them corresponded best to reality. A cartographer produced a map because he was interested in it himself, or for commercial purposes, or because he had been commissioned to do so, following a source map which happened to be available or one which was aesthetically particularly pleasing or one which had just arrived from the Arab-Islamic world. The choice was arbitrary.
One aspect of the methods of work used by a European cartographer between the 14th and 18th centuries is that he had no compunction about inserting a regional map which had come to his attention into a general map or world map, without being able to assess whether the result was correct. The cartographic history of the Caspian provides us with an interesting example of this. It is an amazing fact that the Caspian Sea circulates on regional maps in Europe from the 14th century onwards in the near-perfect shape which had been attained in the 13th century in the Arab-Islamic world. In the 14th and 15th centuries it is represented largely accurately on European world maps, but then disappears (with a few exceptions) from the mapmakers' field of vision in the 16th and 17th centuries, only to resurface in the first quarter of the 18th century.

Relationship of Maps to Coordinates in Europe

This observation is closely connected with the fact that the maps of the Old World compiled in Europe up to the 18th century had not yet been drawn up using coordinates, being inserted into existing graticules by graphically transferring the data of the relevant source maps. Although there were many tables of coordinates in existence in the West which had been taken from the Arab-Islamic world or even been compiled in Europe, they remained, with the exception of some parts of Europe, without any influence on the maps being compiled there. The only attempt known to us, that by Johannes Kepler, to create a link between the coordinates of the tables known to him and the representation of the Old World, was a failure.
Wilhelm Schickard in the 1630s seems to have been the first scholar to come to the conclusion that the maps of the Old World in circulation in Europe, especially as regards the representation of Asia and Africa, were seriously flawed and that he could compile a more accurate map on the basis of Arabic tables of coordinates and on the data contained in Arabic geographical works. My view is that in connection with this it is very significant what the Dutch geographer Willem Janszoon Blaeu wrote to Schickard in 1634: "What you noticed about the longitude between Alexandria and Rome is what I have always thought to be true, in accordance with the observations of our compatriots, that in fact the whole of Europe was represented as too long."
The attempts made by Schickard over many years to find out the coordinates of the book of tables by Abu l-Fidā', so as then to be able to draw up, by using additional Arab geographical works, a more accurate map of the Old World than those current in Europe, show that he did not consider the possibility that it might be more expedient to obtain maps from the Arab-Islamic world and publish them at his own discretion. There can be no doubt that he knew as little as his predecessors and his successors about how and under what conditions the maps circulating in Europe had originated. Indeed, he could not have known that these originally derived from maps from the Arab-Islamic world [**18**] which represented different stages of development and reached Europe more by accident, via many different types of contact—wars, travellers and seafarers, the Crusades or ambassadors. Although there are

Fig. 10: "Persia and adjacent areas", compiled by Adam Olearius in 1637 on the basis of two Arabic regional maps and transliterated into Latin script, as he clearly indicates in his "Vermehrte Moscowitische und Persianische Reisebeschreibung" (Schleswig 1656, p. 434).

older Portuguese, Spanish, Italian or Dutch sources which provide us with clues to this reality, these have not yet had sufficient impact on the awareness of historians of cartography or have in some cases been subjected to arbitrary interpretation and relegated to the realm of legend.

Deliberate Transmission of Arab Maps to Europe

The period of deliberate transmission of maps from the Arab-Islamic world began a few years after the attempt by Schickard mentioned above. According to our present knowledge it was the German scholar Adam Olearius who was the first to unambiguously state that he had converted maps from Arabic script into Latin. Those in question were a map of Persia and one of Anatolia to which his attention had been drawn in 1637 during his stay in Shamakhia (in the Caucasus), together with additional regional maps(*fig.* 10). This kind of transmission of maps from the Arab-Islamic world intensified in Paris between ca. 1650 and 1750 and is thereby linked to the beginning of the creative period of European cartography. In this I am ignoring the repeated clear references by Portuguese seafarers [**20**] since Vasco da Gama that they saw, captured, copied or brought back Arab maps or nautical charts, likewise the remark by the Dutch cartographer Jan Huygen van

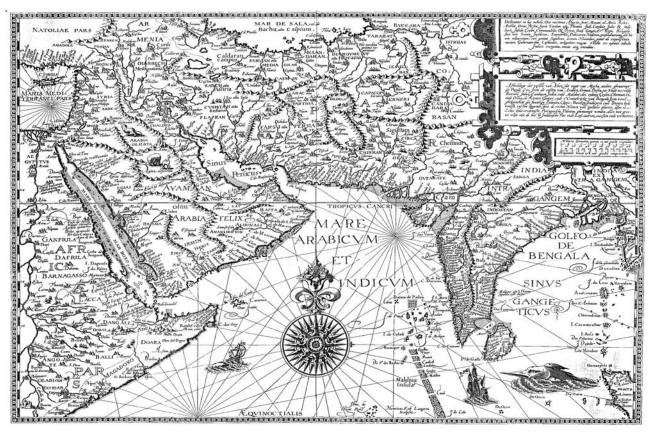
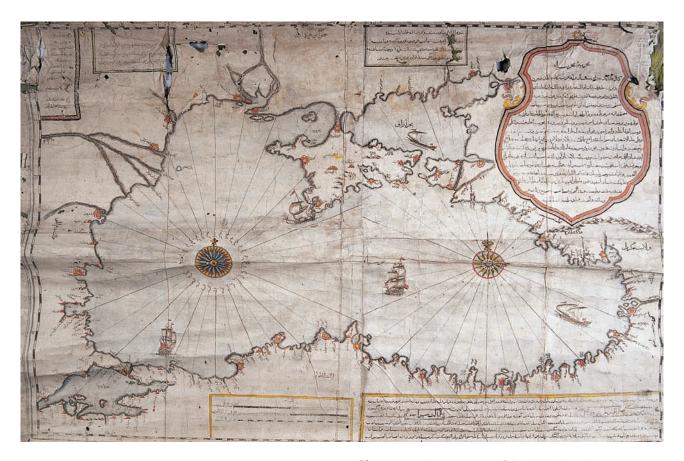



Fig. 11: Map of India and adjacent areas by the Dutchman Jan Huygen van Linschoten (1596), which he himself states was transliterated into Latin script from an Oriental source map. Topography and toponymy of the map leave no room for doubt that the source was an Arabic map.

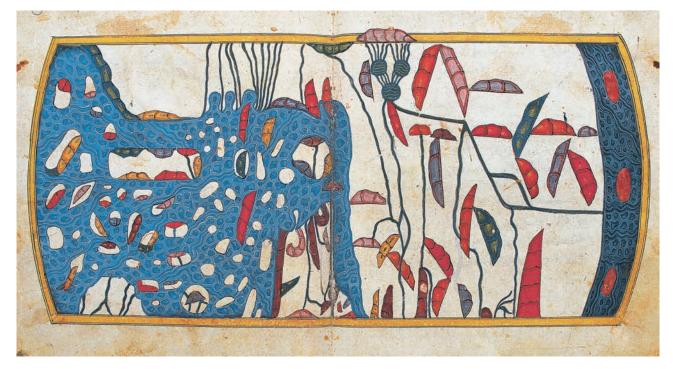
Fig. 12: *Imperii persici delineatio ex scriptis potissimum geographicis arabum et persarum* ['Illustration of the Persian Empire from the writings of the greatest Arab and Persian geographers'] by Adrian Reland (Amsterdam, 1705), one of the European cartographers who expressly mention their Oriental sources. The reason why the northern part of the Caspian Sea, which was not part of the Persian Empire, is missing on the map is probably the fact that Reland used a Persian map as his source.

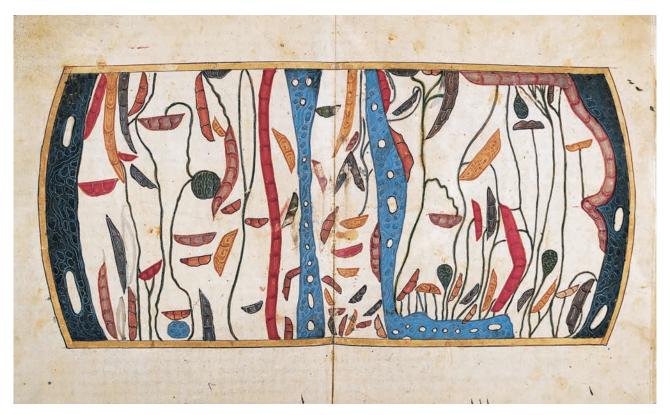
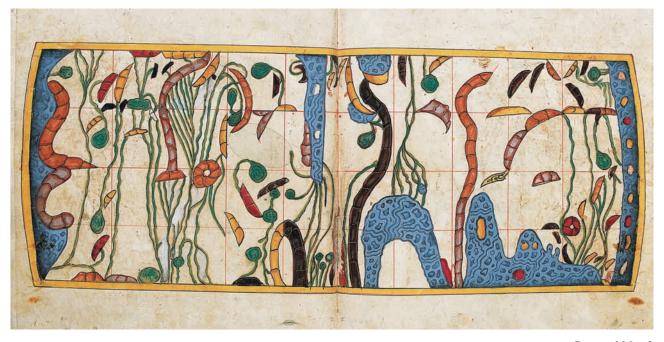
Fig. 13: Exact Ottoman map of the Black Sea whose zero meridian lies 28°30' west of Toledo in the Atlantic, in accordance with Arab-Persian tradition. The longitudes and latitudes given in the margins prove that the representation of the sea by the Ottoman geographers has attained almost perfect dimensions. The French cartographer G. Delisle made use of a copy or of the original of this map, which had reached Paris before 1700.

Linschoten (*fig.* 11) that he had translated the map of South-West Asia and India going by his name from a local language into his own.
The maps by Olearius, those of the Paris school and many of the preceding world maps up to 1560 lead us directly or indirectly to a graticule on which they are based, whose prime meridian lies 28°30' west of Toledo, just as it was fixed half a millennium previously in the Islamic world. If historians of cartography had paid due attention to the indications pointing to this in the graticules of the maps of Adam Olearius, Nicolas Sanson, Adrian Reland (*fig.* 12), Guillaume Delisle, Joseph-Nicolas Delisle (*fig.* 13), Jean-Baptiste Bourguignon d'Anville, Emmanuel Bowen, James Rennell and others and if some of the tables of coordinates accessible in European languages had been compared with the corresponding maps still surviving from the Arab-Islamic world, our discipline would have been spared much futile effort and fruitless discussions.

Terrestrial Globe

made after the
World Map of the Maʾmūn
Geographers

Our model:
Brass, lacquered.
Total height: 1.65 m,
diameter 50 cm.
(Inventory No. A 1.01)

The world map—famous in the history of geography—which had been compiled at the instance of the Abbasid Caliph al-Maʾmūn (ruled 198/813 – 218/833) by many astronomers and geographers and was thought to be lost, was rediscovered at the beginning of the 1980s in the first volume of the encyclopedia *Masālik al-abṣār* by Ibn Faḍlallāh al-ʿUmarī (author's copy of ca. 740/1340) in the Saray Library (III. Ahmet 2797/1) in Istanbul (see above, p. 9). The volume also contains three climata maps of the same provenance. Furthermore, three regional maps, viz. a representation of the course of the Nile, a representation of the Sea of Azov and a representation of the "Isle of Rubies" in South-East Asia are preserved in the University Library at Strasbourg, manuscript No. 4247. This manuscript dates from 428/1036 and contains the book of coordinates of the Maʾmūn geography which a certain Abū Ǧaʿfar [**22**] Muḥammad b. Mūsā al-Ḫwārizmī compiled with the help of the graticule of the world map. It appears that this al-Ḫwārizmī was one of the Maʾmūn geographers, but at present it is not certain whether he is identical with the famous mathematician and astronomer of the same name. The

total number of ca. 3000 coordinates of localities or geographical points allow us to reconstruct the world map completely. The reconstructed map (see above, p. 11) is largely identical with the surviving specimen, which understandably suffered some distortions caused by repeated copying in the course of 500 years. All the same, in my opinion this is the most important of the world maps that have come down to us. Together with the reconstructed map it provides us a cartographic image that to a large extent comes close to the original of the Maʾmūn geographers and thus conveys an idea of the progress mankind achieved in the first third of the 3rd/9th century while documenting the Earth's surface mathematically. For their work the Maʾmūn geographers relied on the achievements of their predecessors as far as they were accessible to them, and perfected these as much as they could within the span of one generation and under the favourable conditions of their time. Their main sources were doubtless the world map of Marinus (1st half of the second century A.D.) und the Geography of Ptolemy (second half of the second century A.D.). It seems the latter did not produce a map himself but only compiled, on the basis of Marinus' map, a cartographic manual which he called Geography. The extant world map shows us the oikoumene in the unmistakable shape of an island, surrounded by a light blue ocean (*al-baḥr al-muḥīṭ*), which itself is surrounded by a mass of dark blue water that is meant to represent the impassable ocean. The map is covered with a globular graticule, contains several scales and gives evidence of the knowledge of the representation of mountain ranges using perspective.[1]

Regional Map 1.

[1] v. F. Sezgin, *Geschichte des arabischen Schrifttums, vol. 10: Mathematische Geographie und Kartographie im Islam und ihr Fortleben im Abendland*, Frankfurt a.M. 2000, pp. 80–129; English version: *Mathematical Geography and Cartography in Islam and their Continuation in the Occident – I: Historical Presentation*, Part 1, Institute for the History of Arabic–Islamic Science, Frankfurt 2005.

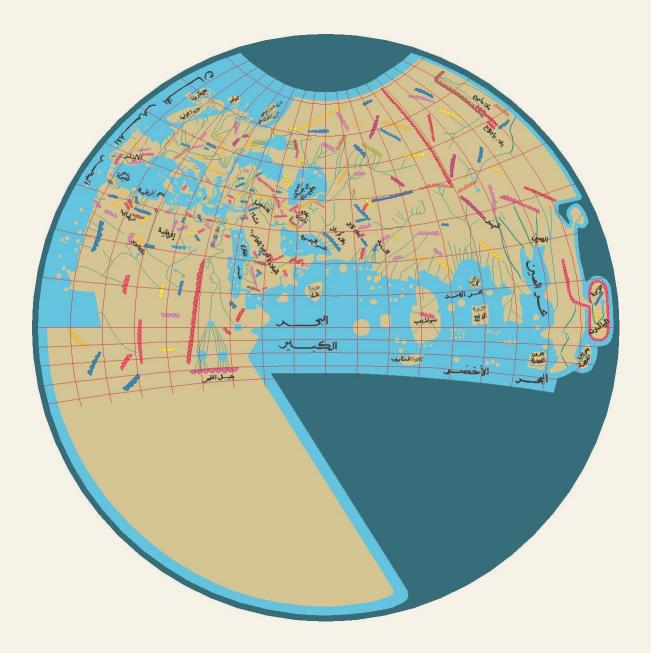
Regional Map 2

Regional Map 3

Fig. above: Regional maps from the Ma'mūn Atlas, preserved in *Masālik al-abṣār* by Ibn Faḍlallāh al-ʿUmarī (author's copy of ca. 740/1340, Istanbul, Topkapı Sarayı, Ahmet III, 2797/1, facs. Frankfurt 1988, p. 292 ff.), here reproduced with orientation on the north.

Regional map 1: First clima showing a part of Africa and the Indian Ocean.

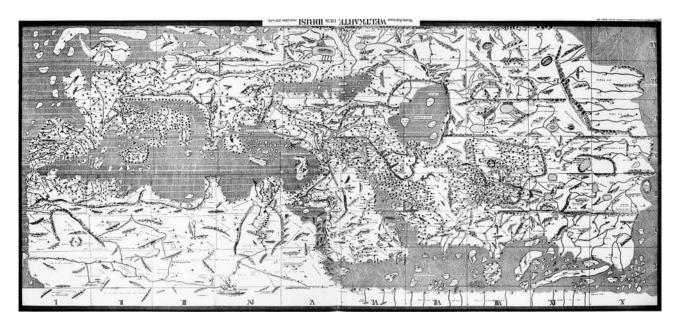
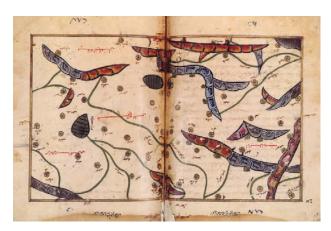
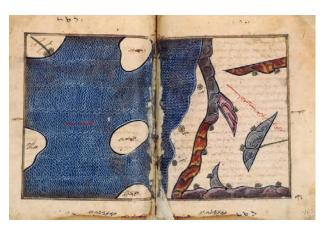
Regional map 2: Second clima showing parts of Africa, the Red Sea, the Arabian Peninsula and Asia.

Regional map 3: Third clima, adjoining the northern regions of the second clima.

The World Map of Caliph al-Ma'mūn (ruled 198-218/813-833)

The Abbasid Caliph al-Ma'mūn (d. 218 H./833 A.D.), who resided in Baghdad and who was greatly interested in the sciences, commissioned during his reign a large group of geographers and astronomers to compile an extensive geographical work and a new world map. Starting from the available world map of Marinus (1st half of the 2nd century A.D:) and the Geography of Ptolemy (2nd half of the 2nd century), the commission was carried out on the basis of contemporary geographical knowledge and by means of data collected by the scholars entrusted with this task by means of geodetic measurements and astronomical-mathematical information. The map of the Ma'mūn geographers was rediscovered some twenty years ago in a copy from the year 740 of the Hijra (1340 A.D.). It is reproduced here. Together with some surviving regional maps from the geographical work and the contemporary tables of coordinates based on the world map which also survive, it opens up an entirely new horizon in the history of cartography. The progress achieved as a result of the ruler's commission can be measured by a comparison with the world map which bears Ptolemy's name. From Baghdad, situated almost at the centre of the known world of the time, the scholars commissioned by al-Ma'mūn

had the advantage [**25**] of compiling South and Central Asia, as well as East and North Africa, as far as possible, using their own observations and measurements. Thus the Maʾmūn map is of epochal significance for various reasons. The second of the maps reproduced above was reconstructed on the basis of the information from the original book of coordinates. Although the later copy no longer reflects the quality of the original, both maps together can clearly show us mankind's achievements in the cartographic representation of the surface of the Earth in the first quarter of the 3rd/9th century. Thus the Maʾmūn map provides us with a solid basis for the evaluation of the further development of cartography, and has in itself become of great importance for this development both in the Arab world and in the Occident. Besides its rather well developed shape of the surface of the Earth, its cartographic tools, such as its globular projection and its cartographic scale as well as the representation of mountains in perspective, help us in bringing forward, to a large extent, our previous dating for the period when these tools originated. Moreover, here the axis of the Mediterranean is reduced to 52° as against a length of 62° or 63° in Ptolemy, Africa can be circumnavigated in the south and Europe and Asia in the north, and both the Indian Ocean and the Atlantic are no longer represented as inland seas, as was the case in Ptolemy.

Metal
World Map
of al-Idrīsī

Our model:
metal, engraved and
lacquered in colour
Diameter: 89 cm.
(Inventory No. A. 1.15)

As a reminiscence of the circular world map engraved on a very large silver plate, made by Muḥammad b. Muḥammad aš-Šarīf al-Idrīsī at the instance of the Norman king Roger II in Sicily (see above, p. 5 ff.), we had the circular map of the world engraved upon a metal plate, having reconstructed it according to the data of the 70 orthogonal regional maps of the *Kitāb Nuzhat al-muštāq fi ḫtirāq al-āfāq* (completed 549/1154) and their transformation into a stereographic projection after being compared with the overview maps preserved in manuscripts.

The well-known rectangular 'World Map of Idrīsī' was compiled from the regional maps by Konrad Miller in 1928; however, Miller did not take the necessary conversion into account, with the result that the north is represented as being as wide as the regions on the Equator, resulting in a configuration of Northern Asia and Africa which is unrecognisable.

World map of Idrīsī, compiled from the regional maps of *Nuzhat al-muštāq* by K. Miller (1928), here reproduced with orientation on the north for the sake of clarity.

Regional maps from the Paris manuscript (Bibl. nat. MS or. 2221), detail of clima 5, showing the Bosphorus up to the Caspian Sea.

Maps of Asia (probably 7th/13th and 10th/16th century) from the French edition of the book by Abu l-Ġāzī Bahādur Ḫān (Leiden 1726), see above, vol. I, p. 130.

CARTE de L'ASIE SEPTENTRIONALE Dans l'Estat où Elle s'est trouvée du temps de la grande Invasion des Tartares dans l'Asie Meridionale sous la Conduite de Zingis-Chan pour servir à l'Histoire Genéalogique des Tatars.

CARTE NOUVELLE de L'ASIE SEPTENTRIONALE dressée Sur des Observations Authentiques et Toutes Nouvelles

Instrument for Measuring Latitudes

on any given day

Our model:
Brass hemisphere, diameter: 36 cm,
graticule of coordinates for each 5°.
Steel gnomon on a concave plate, diameter: 20 cm.
Beech wood cone, height: 21 cm.
(Inventory No. A 1.07)

In the Arabic-Islamic world an instrument was developed, apparently in the first half of the 5th/11th century, which offered two variants for measuring latitudes and could be set up on any given day, without the user needing to have recourse to a table of declinations. This instrument, which is very important from the point of view of enlargement and completion of the geographical tables of coordinates, is described in the fundamental work on mathematical geography by al-Bīrūnī (d. 440/1048), *Taḥdīd nihāyāt al-amākin li-taṣḥīḥ masāfāt*

al-masākin.[1] We are indebted to Muḥammad b. Aḥmad al-Ḫāzimī[2] (fl. ca. 453/1061 in Isfahan), a younger contemporary of al-Bīrūnī, for another description of the instrument.

In the first version of the procedure, a sufficiently large, precisely constructed hemisphere is taken, on which the longitudes and latitudes are inscribed, marking the zenith on it. The great circle of the hemisphere is placed on a horizontal base which has been levelled off precisely by using a plumb line. As an additional tool one makes a cone, whose bottom surface has the diameter of a span. On one side of the cone a window is opened which is large enough to put a hand inside and touch the hole bored in the centre of the base. On the tip of the cone one more hole is bored, a very small one.

Z
P

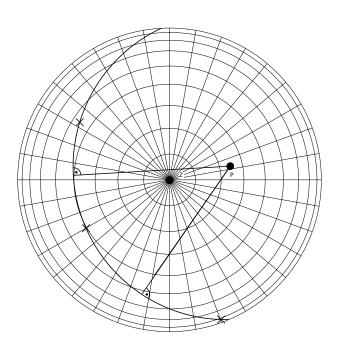
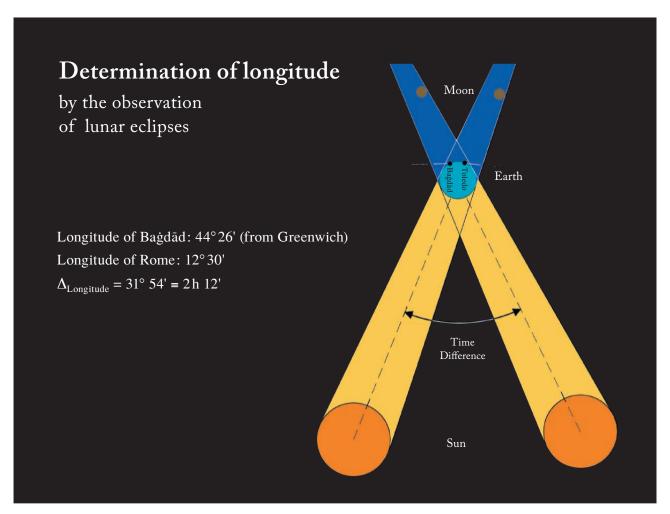
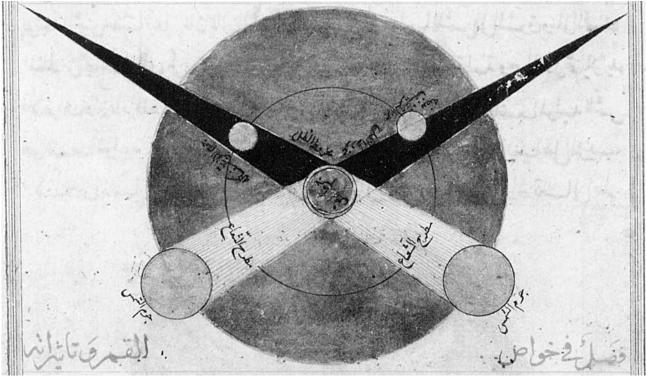
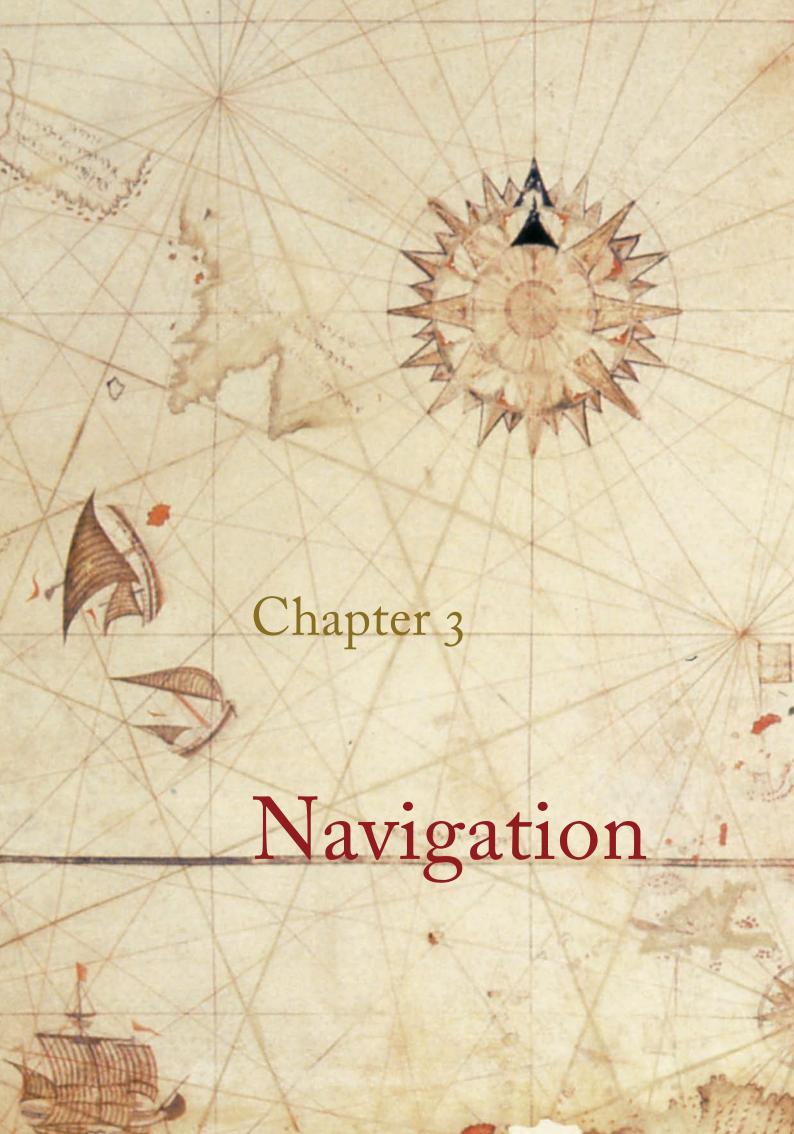



Fig.: Determination of the latitude on the hemisphere.

The cone is placed on the hemisphere, pointed to the sun at any given time during the day, and moved back and forth until the sun's rays fall through the hole at the tip of the cone onto the hole at the centre of the base. That position is marked on the hemisphere (see fig.). The observation of the position of the sun is repeated at different times of the day, resulting in different markings (B, B', B''), which are connected to one another by an arc. The pole (P) of the arc of the great circle thereby ensuing is then determined. This corresponds to the pole of the celestial equator (*muʿaddil an-nahār*), and its distance (a) from the zenith (Z) gives us the complementary angle to 90° and thus the latitude

$$\varphi = 90 - a.$$

In the second version of the procedure, instead of the cone a circular segment is used of the surface of a sphere made of metal or wood, the diameter of which is one or two millimetres larger than that of the hemisphere used above. In the middle of the outer side of this cap, which fits closely on the globe, we affix a gnomon. The cap is moved back and forth on the globe in the direction of the sun until the shadow of the gnomon disappears. This position is indicated on the globe as the centre point of the circle which was first marked around the cap. Two further positions are added with subsequent observations on the same day. Thus, as with the first version, the pole of the celestial equator can be found on the hemisphere and after that the latitude of the place of observation.

[1] Ed. P. Bulgakov, Cairo 1962 (reprint in: Islamic Geography, vol. 25), pp. 71-72; English translation Jamil Ali, *The Determination of the Coordinates of Positions for the Correction of Distances between Cities*, Beirut 1967 (reprint in: Islamic Geography, vol. 26), pp. 41-42: v. also E. S. Kennedy, *A Commentary upon Bīrūnī's Kitāb Taḥdīd al-Amākin*, Beirut 1973 (reprint in: Islamic Geography, vol. 27), pp. 20-22.

[2] Excerpts from a book which he wrote are preserved in a collectanea, Istanbul, University Library, A. Y. 314, facs. ed. *Manuscript of Arabic Mathematical and Astronomical* Treatises, Frankfurt, Institute for the History of Arabic-Islamic Sciences 2001 (series C, vol. 66), pp. 28-29.

Determination of longitude

by the observation
of lunar eclipses

Longitude of Baġdād: 44°26' (from Greenwich)

Longitude of Rome: 12°30'

$\Delta_{\text{Longitude}}$ = 31° 54' ≡ 2h 12'

Moon

Earth

Baġdād

Toledo

Time
Difference

Sun

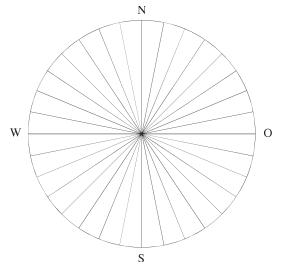
Representation of eclipses from al-Qazwīnī, *ʿAǧāʾib al-maḫlūqāt*, 7th/13th c.;
MS Wien, Nat. Bibl. Cod. mixt. 311, fol. 3b.

Chapter 3

Navigation

Know that there are three classes of navigators: those whose voyage goes off well one time and another time not, whose answer is right one time and wrong the next. These do not deserve the title of "master". In the second class there are the navigators who are known for their practical knowledge and experience. They are skilful and fully conversant with the routes which they have sailed, but after their death they sink into oblivion. The third class is the highest. Whoever belongs to it is famous, masters all operations at sea and writes treatises which people make use of during their lifetime and even later.

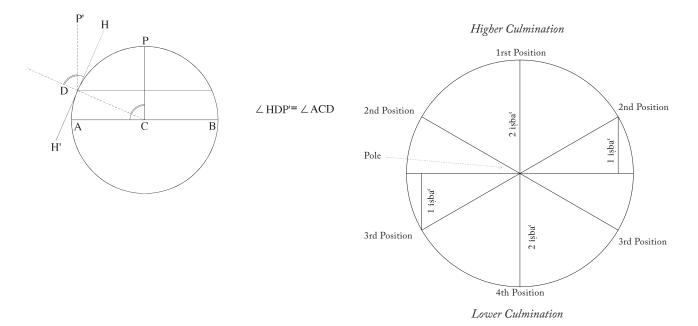
Ibn Māğid (2nd half of the 9th/15th century)

Introduction

The relevant research in this field, particularly in the latter half of the 20th century, has established that as early as the middle of the 1st/7th century approximately the Muslims began to attack and conquer islands in the east of the Mediterranean with their own fleets, growing into a formidable sea power within a short time in the southern Mediterranean and later in the entire region of the Mediterranean.[1] That the sea-borne traffic between the Muslims and China also goes back to the 1st/7th century and that it continued to expand throughout the centuries had long been known to research.[2] In his excellent work *L'océan Atlantique musulman*,[3] Christophe Picard explained that the development of Arab-Islamic seafaring in the Atlantic along the ca. 1300 km long strip of coast from Coimbra in the north to Nūl (today probably Noun) in the south was very important from the time of the Arab conquest up to the rule of the Almohads (1130-1269). It must, however, be emphasised that these works generally deal with the historical aspect of the seafaring undertaken by Arabs and Muslims in the great basins mentioned, not being concerned with the techniques employed. That is why we know hardly anything now about the seafaring techniques of the Muslims in the Mediterranean and in the Atlantic. By contrast, in the case of the Indian Ocean, we know that navigation was quite well developed, thanks to special research begun in the early 19th century. In the eleventh volume of my *Geschichte des arabischen Schrifttums*, dealing with the *Mathematische Geographie und Kartographie im Islam und ihr Fortleben im Abendland*,[4] I wrote extensively about this navigation and its influence on the nautical knowledge of the Portuguese. Some aspects of this may be mentioned here.

We can almost certainly assume that contacts across the sea between the peoples living along the western and eastern littoral of the Indian Ocean for a long time hugged the coastlines. After some time, however, they must have felt emboldened to cover longer distances across the high seas. We do not know when, how and among which seafarers this happened. Arabic sources permit us to assume that use was made of the rising and setting of certain fixed stars, of the position of the Pole Star and other circumpolar stars for orientation at sea. In the course of development of this system of orientation, sailors began to take their bearings not only on the North Star and Southern Cross, but also on 15 fixed stars whose points of rising and setting are at a distance of ca. 11° 15' to each other, which led to a division of the circle of the horizon into 32 parts: At a relatively high level of development the awareness emerged that the astronomers and mathematically inclined geographers divided the Earth's surface northwards and southwards from the equator into 90° each and the longitudes into 360°. This may have led to the desire for a determination of the position on the high seas in degrees, which apparently had hitherto only been estimated in a rough and ready way on the basis of the time elapsed and the distance covered in the time since putting out to sea. In this [**36**] connection, they must have acquired the astronomical knowledge, known already to the ancient Greeks, that the altitude of the pole (P) at a point (D) on the Earth's surface (angle HDP') is equal to its latitude (angle ACD).[5]

N
W
O
S

Division of the circle of the horizon into 32 parts.

[1] On the literature, v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 11, pp. 5 ff.

[2] On the literature, v. ibid., vol. 10, pp. 546-547, also George Fadlo Hourani, *Arab seafaring in the Indian Ocean in ancient and early medieval times*, Princeton 1951.

[3] *L'océan Atlantique musulman. De la conquête arabe à l'époque almohade*, Paris 1997; v. F. Sezgin, op. cit., vol. 11, pp. 11-12.

[4] *Geschichte des arabischen Schrifttums*, vol. 11, pp. 159–319.

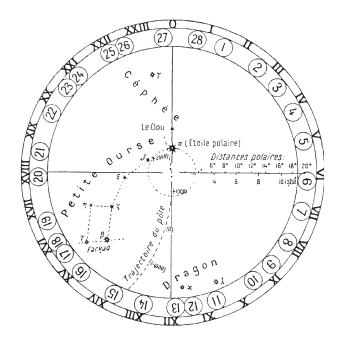
[5] F. Sezgin, op. cit., vol. 11, p. 188.

P' H P D A C B H'

∠ HDP'= ∠ ACD

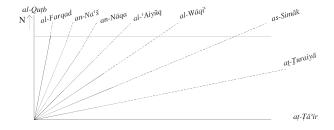
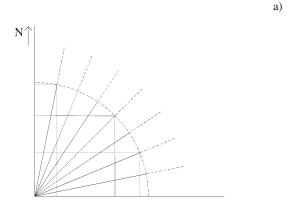
Higher Culmination
1rst Position
2nd Position
2nd Position
2 iṣbaʿ
1 iṣbaʿ
Pole
1 iṣbaʿ
2 iṣbaʿ
3rd Position
3rd Position
4th Position
Lower Culmination

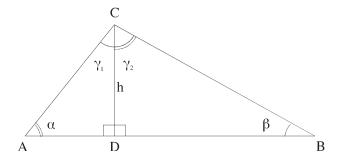
The navigators of the Indian Ocean will have learnt either through their own experience, but more likely from Arab astronomers, that the pole as an abstract point does not coincide with the Pole Star, but that once a day the latter describes around the former an (apparent) circle with a radius of ca. 3°25',[6] which changes in the course of time, and that while establishing the height of the pole the altitude of the Pole Star has to be taken into account, which is variable because of the rotation. This means that the observed altitude of the Pole Star has to be reduced to the altitude of the celestial pole itself. For this they had at their disposal the method of Arab astronomers, known since the 3rd/9th century, of calculating the true distance of circumpolar stars to the celestial pole by halving the difference between their upper and lower culmination heights as elicited.[7] "In contrast to the astronomer, who fulfilled this task mainly by observing and measuring the hour angle between the position of the Pole Star in the meridian and its right ascension or the position of a circumpolar star relative to the meridian,[8] the sailor needed to overcome his problem by observing additional fixed points in the sky. In doing this at first the two stars β and γ were used, which according to the contemporary astronomical view were joined to the Pole Star α in the constellation of Ursa Minor by a fixed link. These two, known as *al-Farqadān*, made it possible to determine the position of the celestial pole by virtue of their known distances and the positions forming horizontal and vertical lines, which fluctuated jointly. To be on the safe side, though also to facilitate the determination of the position of the celestial pole, seafarers in the Indian Ocean also employed specific times of rising and setting of the twenty-eight lunar stations (*manāzil al-qamar*) as an additional aid. The rising of specific lunar stations provided evidence that one of the fixed positions of the two stars β and γ of Ursa Minor relative to the pole is accurate, and they revealed the time when those positions are taken up as part of the apparent diurnal rotation of the firmament, since the lunar stations in the ecliptic follow this apparent diurnal rotation."

[**37**] In the figure which we added here, "the 12th lunar station … is in the descendant. Its 'guardian', the 26th lunar station, … is located opposite at 180° in the ascendant. In this constellation the Pole Star reaches its highest culmination. By contrast, the setting of the 26th and the rising of the 12th lunar station point to the fact that the Pole Star is in its lower culmination."[9]

The determination of the position of the North Pole enabled the sailor not only to measure the height of the pole more precisely and thereby his latitudinal position on the high seas, but also, while sailing

[6] F. Sezgin, *Geschichte des arabischen Schrifttums,* op. cit., vol. 11, p. 188–189.
[7] Ibid., vol. 11, p. 191–192.
[8] Ibid., vol. 10, p. 169
[9] ibid, vol. 11, pp. 189-190.

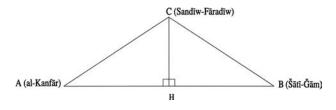
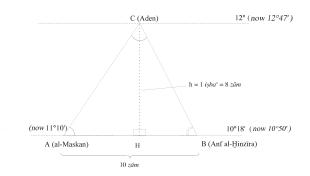
meridionally, to ascertain the distance traversed in degrees.
This was only one of the factors which made possible a safe passage across the Indian Ocean in all directions and a fairly precise determination of the position at sea. But under a cloudy sky an orientation by the stars or by the sun was not possible. In that case another aid was needed. It was the compass. Our Arabic sources permit us to assume that the compass was known to the Arab sailors in the Indian Ocean by the 4th/10th century, perhaps even by the 3rd/9th century. It is very likely that the knowledge of the magnetic needle as a means of orientation reached the Indian Ocean from China. We can take it as certain that the compass served the sailors in the Indian Ocean not only as an aid for orientation, but also for the determination of distances on the high seas and was being used for the compilation and correction of map material before the 10th/16th century, perhaps even in the 8th/14th or the 7th/13th century. While studying the geography and navigation of the Indian Ocean, we became convinced that the cartographic representation of this area and the work on the longitudes and latitudes required for this had reached a high level by the 9th/15th century. This leads to the question of the determination of longitudinal positions on the high seas, and here we see a fundamental achievement of Arabic-Islamic navigation.

Towards the end of the 19th century, when Wilhelm Tomaschek was able to compile, on the basis of the limited second-hand material then known, so much data about distances and directions that he was able to reconstruct 30 regional maps of the Indian Ocean, he astounded the scholarly world. In his view these data had, however, been obtained "by thousand-fold trial and error".[10] This fundamental problem of Arab navigation could be solved only after the discovery and thorough study of its specialised works, particularly those by Sulaimān al-Mahrī (early 10th/16th c.).
While referring to the excellent study by Matthias Schramm[11] and to the detailed treatment of the topic in the *Geschichte des arabischen Schrifttums*,[12] we may here list the methods of Arab navigation which served to determine three kinds of distances by measuring the covered distances on the high seas, measured in Arabic miles (1 *mīl* ≈ 1972 m):
[**38**] 1. The seafarer measures meridional distances which a ship covers in a north-south direction or vice versa parallel to a meridian by determining the pole altitude of his point of departure when setting out, and by measuring again, as the need arises, the pole altitude of his destination after sailing strictly towards the north or the south. The difference between the two measurements yields the distance covered in degrees.
2. Determination of distances oblique to the meridian. Here too the seafarer first of all determines the pole altitude at the point of departure. After covering a certain distance, while maintaining a predetermined course (either according to one of the points of direction of the compass disc, divided into 32 segments, or according to the corresponding point of the rising or setting of one of the fifteen known fixed stars), he determines the pole altitude once again. The resulting difference between the two pole altitudes and the course determined at departure gives the navigator one side and one of the two adjacent angles of a right-angled triangle, whose hypotenuse, which has to be calculated trigonometrically, represents the length of the distance traversed.
3. Determination of distances between two places lying on the same geographical latitude, but on op-

[10] ibid, vol. 11, p. 198.
[11] *Verfahren arabischer Nautiker zur Messung von Distanzen im Indischen Ozean*, in: Zeitschrift für Geschichte der arabisch-islamischen Wissenschaften (Frankfurt) 13/1999-2000/1-55.
[12] F. Sezgin, op. cit., vol. 11, pp. 198 ff.

posite coasts. What are involved here are distances running parallel to the Equator. With this type of measurement of distance, which amounts to a determination of longitudinal difference, the problem is solved by a type of triangulation. After the exact determination of the pole altitude at departure the navigator maintains an elicited angle, which is oblique to the meridian, until a certain point is reached where the pole altitude is again measured.

Calculation of distances oblique to the meridian:
a) Points of directions of the circle of the horizon.
b) Calculation of the square.

From there he sails at a certain angle opposite to the course followed so far, until he once again reaches the same pole altitude which was registered at departure. With the angles of the course maintained and the elicited difference in pole altitudes, the seafarer simulates two right-angled triangles with a common side, which is constituted by the elicited difference in pole altitudes.

AC = first course
$\overline{CD}$ = difference in pole altitudes
$\overline{CB}$ = second course
$\overline{AB}$ = distance to be measured

The seafarer could repeat this triangulation as many times as he wished. We may add here that among the navigators of the Indian Ocean the custom became established of stating distances by using a measure of length called *zām*, which corresponded to 23.851 metres or 4.77 new Portuguese leguas.[13] This measure of length was one eighth of the distance that could be covered by ship in a day [**39**] and night, implying a voyage of three hours,[14] as our Arabic sources state. From this we can conclude that the ships in the Indian Ocean could cover a distance of ca. 190 km per day (i.e. a mean speed of almost 5 knots) and took ca. 32 days for the voyage between East Africa and Sumatra along the Equator (ca. 57° = 6330 km).
To make this overview intelligible, it is also necessary to mention the measure of the arc, the *iṣbaʿ*, which literally means “thumb’s width”, and which was used by the navigators of the Indian Ocean. This measure, whose practical usefulness cannot be denied may have been known before Arabic astronomy became known, perhaps even before the appearance of the Arab navigators in the Indian Ocean. The *iṣbaʿ* is a part of a circle divided into 224 or 210 degrees. According to the first division, one *iṣbaʿ* is equal to 1°36'26", according to the second 1°42'51".[15]
After these introductory explanations, we may cite here the two classic examples of Arab navigation in the Indian Ocean to illustrate the method of measuring distances on the high seas which are parallel

[13] *Die topographischen Capitel des indischen Seespiegels Moḥîṭ*. Translated by M. Bittner. With an introduction … by W. Tomaschek, Vienna 1897, p. 22 (reprint in: Islamic Geography, vol. 16, Frankfurt 1992, p. 156).
[14] v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 11, p. 201.
[15] ibid, vol. 11, p. 194.

to the Equator. The first example "involves three places in the Gulf of Bengal which form an equilateral triangle with the latitudes given (twice 11 *iṣbaʿ* = 22°18' and once 11 1/2 *iṣbaʿ* = 23°09'). The size of the two (identical) base angles is given according to the position of the places facing the rising or setting point of a fixed star, which is 22°30' according to the corresponding 11th or 23rd point of the compass rose":

∠ HAC = HBC = 22°30'

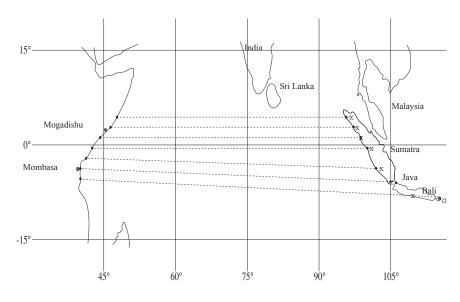
The second example refers to the Arabian Sea. It says: 'There are two courses, [one] between Aden [5 *iṣbaʿ* according to the lower culmination of the Pole Star = 12°] and Anf al-Ḫinzīra at 4 *iṣbaʿ* [= 10° 18'] at the rising of the Suhail [Canopus, α Argus] and [the other] between Aden and al-Maskan, also at 4 *iṣbaʿ* at the setting of the *Ḥimārān* (the two donkeys, α and β Centauri). The distance determined between the two places [Anf al-Ḫinzīra and al-Maskan] is 10 *zām*.'

∠ CAB = 56°15'
(based on the 20th point of the compass rose).
∠ ABC = 67°30'
(based on the 15th point of the compass rose).
∠ ACB = 56°15'= ∠ CAB.

Despite the deviations of the latitudes from today's values, the distance determined, viz. 10 *zām* = 283.56 km, seems to correspond approximately to the value of the modern map of (45°50' - 43°37' =) 2°13'."[16]

The Arab navigators "preserve for us fairly long tables for short and long distances in the Indian Ocean in the corresponding chapters of their books. When compared with today's values their data prove largely to be very good, sometimes relatively good, and sometimes, where they refer to less frequented areas, to be erroneous. Yet on the whole, together with the latitudes and the directions given, they reveal [**40**] a mathematical record of the Indian Ocean which accords astonishingly closely with reality … In the fourth chapter of his *Minhāǧ al-fāḫir* Sulaimān al-Mahrī gives us clear information about the question of how far the mathematical record of the configuration of the Indian Ocean had progressed in the Arab-Islamic world and how successfully the seafarers operated with their measurement of distances. There, in a section exclusively devoted to distances between the east coast of Africa and Sumatra – Java, he lists 60 distances between headlands, gulfs, islands and ports in the Indian Ocean which are located on the same geographical latitudes. Over 60 years ago G. Ferrand pointed to the importance of the materials provided by Sulaimān al-Mahrī on the (transoceanic) distances between the East African coast and Java – Sumatra. Unfortunately his comment was ignored, as far as I can see, by historians of geography and cartography, with the exception of H. Grosset-Grange."[17]

"Under no circumstances does the extraordinarily great significance of this table by Sulaimān al-Mahrī for the history of geography depend simply on what was indicated by G. Ferrand. The table really only comes into its own when its data are compared with today's coordinates. The comparison is scarcely impaired by the fact that not all the ancient names can be identified in a modern atlas. Even without place names we would have been able to carry out a comparison, since al-Mahrī recorded distances between corresponding latitudes at opposing points of the African and the Sumatran-Javanese coasts. If we convert the sums given by Sulaimān al-Mahrī from *zām*s … into degrees, we arrive at the values in the following table:[18]

[16] F. Sezgin, op.cit., vol. 11, pp. 211-213.

[17] ibid, vol. 11, pp. 211-214.

[18] ibid, vol. 11, p. 215.

			Al-Mahrī			Modern Values					
	Point on the African coast	Point on the coast of Sumatra/Java	Lat.	Distance in *zām*	Distance in degrees	Lat.	Long.	Lat.	Long.	Distance in degrees	Deviation
1	Muqbil Atoll (Mareek?)	Mākūfānğ (Meulaboh)	4°24'	234	50°09'	3°46'	47°15'	4°10'	96°09'	48°54'	**+1°15'**
2	Murūtī	Fanṣūr (Barus)	2°47'	248	53°09'	(2°47')	46°21'	2' 02'	98°20'	51°59'	**+1°10'**
3	Barāwa	Priaman	1°10'	264	56°34'	1°02'	44°02'	S 36'	100°	55°58'	**+0°36'**
4	Malawān (Imāma)	Indrapura	S 0°30'	278	59°34'	S 0°03'	42°44'	S 2°02'	100°56'	58°12'	**+1°22'**
5	Kitāwa (Pale Island)	Sundabari (Sillebar)	S 2°07'	292	62°34'	S 2°04'	41°05'	S 4°10'	102°20'	61°15'	**+1°19'**
6	Mombasa	Sunda (Šūnda)	S 3°44'	306	65°34'	S 4°04'	39°40'	S 6°	106°	66°20'	**−1°14'**
7	Ğazīrat al-Ḫaḍrāʾ (Pemba)	Bali	S 5°21'	317	67°56'	(S 5°21')	39°44'	S 8°	115°	75°16'	**−7°20'**

Distances of places with corresponding degrees of latitude on the east coast of Africa and in Java/Sumatra according to Sulaimān al-Mahrī and the modern map.

"In order to properly grasp the importance of the distances listed by al-Mahrī for the history of geography, cartography and navigation, we need to look at how they diverge from the corresponding modern values (cf. the adjacent figure).

(Distances between Africa and South-East Asia according to Sulaimān al-Mahrī, with reference to modern maps)

[**41**] "The largest divergence (-7°20') seems too large to us nowadays; the second largest ones (1°22' and 1°21'), also at first glance, spoil the high quality of the other, more correct values. However, the precision we are dealing with is one involving values of distances of ca. 5500-8000 kilometres on the open seas, i.e. of transoceanic differences in longitude of between 50° and 75°, not one which could be achieved in a densely populated area by means of surveying or by calculations deriving from thousands of ships' voyages along the coast. The data cover the Indian Ocean between Lat. 4°24' north and Lat. 5°21' south and provide us with coordinates of a large part of this ocean determined on a purely nautical and mathematical basis. The figures can scarcely be regarded as coincidental, the more so since they constitute differences in longitude whose accuracy or proportions of divergence were only discovered after centuries of work.
Their more recent successors do not keep us in the dark about their methods. They know the traditional

astronomical method of determining differences of longitude by using lunar eclipses, and they know the method of dead reckoning used by seafarers, but they do not rely on these methods and their results. As navigators they were not only responsible for the courses of ships, but also at the same time, as superb experts in the astronomy, mathematics etc. cultivated in the Arab world, they developed their own method of triangulation, whereby two of the sides of a triangle were linked, on the one hand longitudinally with terrestrial points and on the other hand latitudinally with circumpolar stars. They knew how to determine their distance from the Equator from the altitude of the pole and their direction on the basis of specific fixed stars (which they were able to achieve in the course of time by means of a sophisticated compass). Thus the condition was met for moving on to triangulation."[19]

After these brief remarks on the nature of Arab navigation in the Indian Ocean, we may add a few words about its representatives. We learn about Arab navigation through the works of its two greatest exponents, Ibn Māǧid and Sulaimān al-Mahrī, from the first half of the 9th/15th and the first quarter of the 10th/16th centuries. Recent research first received some idea of their importance through the excerpts from their works in the *Kitāb al-Muḥīṭ* of the Ottoman admiral Sīdī ʿAlī (d. 970/1562), which have been made available and studied in parts since 1834. The discovery of the extant original texts, their publication, partial translation and study only occurred in the course of the 20th century. Not often, but every now and then, we also hear in these writings something about their predecessors. Ibn Māǧid mentions the works of several navigators who were active in the 4th/10th century and whom he calls authors who had not yet presented their material systematically.[20] According to Ibn Māǧid, the elder of the two, navigation is "a theoretical and empirical science, not simply one caught up in a paper tradition, *ʿilm ʿaqlī taǧrībī lā naqlī*. He divides the seafarers into three groups: the first are the ordinary pilots whose navigation sometimes works and at other times does not, whose answers are sometimes right and sometimes wrong. These are the sailors who do not deserve to be called *muʿallim*. Those belonging to the second category, the ordinary *maʿālima*, are known for the size and the range of their knowledge; they are skilful, are familiar with the routes of the places to which they sail, but when they die they are forgotten. The third class of seafarers is the best. Whoever belongs to this class is very well known, is familiar with all navigational operations and is a scholar who 'writes texts' which are useful in his lifetime and after. Ibn Māǧid lays down the regulations which a captain needs to observe on his voyage and the moral principles to be expected of him."[21]

"According to Sulaimān al-Mahrī the nature of nautical science (*aṣl ʿilm al-baḥr*) consists of theory (*naẓar al-ʿaql*) and empiricism (taǧriba). These are the two bases: what is tested and agrees with the theory is correct and reliable … According to Sulaimān al-Mahrī, the discipline is subject to the law of change (*qānūn at-tadrīǧ fi l-farʿīyāt*), particularly as regards the details, [**42**] whereas the basic outlines can be regarded as being approximately correct (*maʿa ṣiḥḥat qarīnat al-aṣl*). Ibn Māǧid is convinced that he himself has developed a great deal in the subject, but that in his earlier works he has also written things which need to be corrected."[22]

Both navigators were well acquainted with many sciences of the Arab-Islamic world and possessed a high degree of knowledge, particularly of Arab astronomy, which was indispensable in their special field.[23] They knew and carried on their ships the main astronomical instruments for measuring altitudes, such as the astrolabe and the quadrant, and worked with them when the need arose.[24] However, the instruments with which they were better acquainted and which were more functional for them were the instrument known in Europe as Jacob's staff and—particularly among Portuguese seafarers—as *balestilha*, and the compass. Thanks to its easy usability for the determination of latitudes according to the pole altitude, the former was a suitable instrument for the navigators of the Indian Ocean while navigating on the high seas. The astrolabe, on the other hand, was more suitable for use on land, for the measurement of the latitudes of places, while on board a rocking boat errors of up to 5° or 6° had to be anticipated when measuring altitudes with the astrolabe. The instrument marked in *iṣbaʿ*s (thumb's widths) was known to earlier Arab navigators as *ḫašabāt* (boards) or *ḫaṭabāt* (wooden plates). The number of plates was prefer-

[19] F. Sezgin, op. cit., vol. 11, pp. 216-218.
[20] ibid, vol. 11, p. 179.
[21] ibid, vol. 11, p. 177.
[22] F. Sezgin, op. cit., vol. 11, p. 178.
[23] ibid, vol. 11, pp. 180-181.
[24] ibid, vol. 11, pp. 225-227.

ably twelve, according to Ibn Māǧid, and they were available in larger, medium and smaller formats. The instrument was known as *kamāl* (the perfect one) in later centuries.[25]

[**43**] In this connection I cite the famous report from the Asia of the Portuguese historian and geographer João de Barros (1490-1570) about the meeting between Vasco da Gama and the Muslim sailor Malemo (*muʿallim*, "master") Caná, a native from Gujerat, on the south-east coast of Africa. The report also gives information about the character of the Arabic graduated maps of the Indian Ocean: "Among them came a Moor, a Guzarate by birth, by the name of Malemo Caná, who agreed to travel with them both because of the pleasure that our company afforded him and as a favour to the king, who was looking for a pilot for them. However, when Vasco da Gama had dealings with him he was very much content with the man's knowledge, especially when he showed him a map of the whole coast of India, which was divided up, in the manner of the Moors, into very small meridians and parallels of latitude, without any compass rose. Since the rectangle of these meridians and latitudes was very small, the coast was very exactly represented by those two gradations from north to south and east to west, without containing the multiplication of the winds of the normal compass of our chart, which serves as a basis for the others. And when Vasco da Gama showed him the large wooden astrolabe and other metal astrolabes which he used to record the altitude of the sun, the Moor was not at all surprised, saying that some helmsmen (pilots) on the Red Sea employed triangular instruments of tin and quadrants whereby they recorded the altitude of the sun and the star which they particularly needed for navigation, whereas he and the sailors of Cambaya and all of India recorded their distance with a different instrument, not with those, because their navigation was dependent both on specific stars, from north to south and also on other large stars which pass across the firmament from east to west. He showed this instrument to him at once, and it consisted of three plates."

"And because in our *Geographia* [*universalis*] in the chapter on nautical instruments we deal with

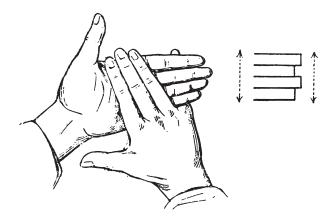



Fig. Measurement of one *ḏubbān* = 4 *iṣbaʿ* with the fingers of the hand (after Léopold de Saussure).

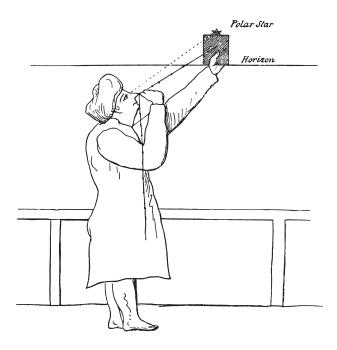



Fig.A traditional device for determining the latitude in the Indian Ocean (after H. Congreve).[26]

[25] F. Sezgin, op. cit., vol. 11, p. 230; v. Léopold de Saussure, *Commentaire des Instructions nautiques de Ibn Mājid et Sulaymān al-Mahrī*, in: Gabriel Ferrand, *Introduction à l'astronomie nautique arabe*, Paris 1928, pp. 129-175, esp. p. 162 (reprint: Islamic Geography, vol. 21, Frankfurt 1992, pp. 191-237, esp. p. 224).

[26] H. Congreve, *A Brief Notice on Some Contrivances Practiced by the Native Mariners of the Coromandal Coast in Navigation, Sailing, and Repairing their Vessels*, in: Gabriel Ferrand, *Introduction à l'astronomie nautique arabe*, Paris 1928 (reprint: Frankfurt 1986), p. 26; F. Sezgin, op. cit., vol. 11, p. 230.

the shape and the use of the same, it may suffice here to know that they serve them in the operation for which we use an instrument which seafarers call Jacob's staff and about which we shall likewise speak in the chapter cited as well as of its inventors."[27]

Now I come to the second main instrument of navigation in the Indian Ocean, the compass, one of the basic components of navigation on the high seas mentioned above (p. 37 ff.). According to the impression created by the works of Ibn Māǧid and Sulaimān al-Mahrī, navigation on the high seas was based on the system of the compass, at the latest in the 9th/15th century, and probably even earlier. The compass did not replace the older system of orientation by fixed stars, but improved and enlarged it. The division of the plane of the horizon into 32 parts of the old system was retained and complemented by the division into 360 degrees. The navigators in the Indian Ocean called the arcs of the division of the circle of the horizon into 32 parts, which at the same time show the angle of the course, *ḫann* (plural *aḫnān*). In this word we find the origin of the term rumb, which occurs in European languages in different forms.[28] The compass was either referred to as ḥuqqa ("box") or *bait al-ibra* ("box of the nail, lit. house of the needle"), the needle itself being ibra or *samaka* ("fish").[29] We may conclude, from statements which are not quite unambiguous, that at least the two great navigators knew the deviations of the magnetic needle.[30] This assumption is supported by the fact that the Ottoman admiral Sīdī ʿAlī (d. 970/1562), who summarised the works of the two navigators (see above, p. 41) in a tract about a special sundial (*dāʾire-yi muʿaddil an-nahār*, see above, II, 158 ff.), shows himself to be conversant with the magnetic deviation and determines it for Istanbul at 7° (ibid, p. 159).

The Arab navigators tell us less about the forms of the compass than about its uses. [**44**] However, the information gap regarding the forms is bridged, to a large extent, by the Portuguese sources. The oldest Portuguese report about the compass used in the Indian Ocean goes back to Vasco da Gama. He narrates with astonishment that "magnetic needles after the manner of the Genoese" are used there, besides quadrants and sea charts.[31] This statement is particularly important for us because we can infer from it that the advanced type of the compass from the Indian Ocean reached Europe before the first Portuguese expedition. The Genoese, Christopher Columbus, carried a similar one with him.[32]

The most detailed description of the three types of the compass used in the Indian Ocean is given by the Portuguese historian Hieronimus Osorius (1506-1580). He even informs us about the different stages of their development.[33] His information enabled us to reconstruct all three types completely (see below, p. 61 ff.). The most developed of the three is the one that continued to be in circulation in Europe up to the 19th century. Its main characteristic is that the entire compass disk with the 32 markings, suspended according to the system subsequently known as "Cardanic", rotates together with the magnetic needle fixed below. With the even more advanced type, which Ibn Māǧid refers to as his own invention, the magnetic needle does not move the compass disk from below, but rotates freely suspended above it[34] (see below, p. 65).

Now we come to speak briefly about the remaining third component of navigation on the high seas, the graduated chart, without which the determination of positions would not be possible. Referring the reader to the Geschichte des arabischen Schrifttums[35] for the treatment of this question and without repeating the arguments here, I will summarise the result achieved there, namely that within the Indian Ocean a highly sophisticated type of graduated sea chart was developed, which can only be understood as the product of an interplay over centuries between a familiar mathematical geography and a highly developed astronomical navigation. Not only the data of Arabic-Turkish sources create this impression, but also the testimony of the Portuguese and other European seafarers and the

[27] J. de Barros, *Asia*, Década I, Liv. IV, Cap. VI (Ed. Lisbon 1946, pp. 151-152); *Die Asia des …, in wortgetreuer Übertragung* by E. Feust, Nuremberg 1844 (reprint in: The Islamic World in Foreign Travel Accounts, Frankfurt 1995, vol. 53), p. 130; cf. J.-T. Reinaud, *Géographie d'Aboulféda*, vol. 1: *Introduction générale*, Paris 1848 (reprint in: Islamic Geography, vol. 277), pp. 439-440; A. E. Nordenskiöld, *Periplus*, Stockholm 1897, p. 147; G. Ferrand, *Introduction à l'astronomie nautique arabe*, op. cit., pp. 192-194; F. Sezgin, op. cit., vol. 11, pp. 227-228.

[28] v. F. Sezgin, op. cit., vol. 11, p. 234.

[29] ibid, vol. 11, p. 234.

[30] ibid, vol. 11, p. 236.

[31] F. Sezgin, op. cit., vol. 11, p. 307.

[32] ibid, vol. 11, pp. 252-253.

[33] ibid, vol. 11, pp. 253-256.

[34] ibid, vol. 11, p. 261.

[35] Vol. 11, pp. 265-268, 323-336.

studies of the extant map material. The Portuguese encountered not only a wealth of highly developed cartographic material, but also an advanced type of astronomical navigation. Moreover, according to their own accounts, the Portuguese were stimulated and encouraged to set out on their expeditions by the maps which reached them from those distant regions. When we notice on a Portuguese world map, probably dating from the years 1519-1520, which is provided with longitudes and latitudes (and is ascribed to Jorge Reinel),[36] that the distance between the east coast of Africa and the west coast of Sumatra is 57° at the Equator and differs from the modern value (56°50') by a mere 10' and is, on the other hand, only 20' away from the value of the Arab navigator Sulaimān al-Mahrī, we can presume that the Portuguese map maker must have had a model at his disposal, which, at least with regard to the Indian Ocean, can have only originated locally, and that only after centuries of continuous activity.

[36] ibid, vol. 11, pp. 398-400.

A measuring Instrument
for determining altitudes at sea

Our model: Hardwood.
Three square plates.
Thread with knots
at regular intervals.
(Inventory No. C 2.08)8)

From a report by the Portuguese historian João de Barros, we gather, inter alia, that the seafarers of the Indian Ocean found those instruments which served astronomers on the mainland for the measurement of altitudes inconvenient on board pitching and rolling ships. He states that on his first expedition Vasco da Gama had shown his Muslim pilot "the large wooden astrolabe and other metal astrolabes which he used to record the altitude of the sun." The "Moor" was not at all surprised, "but said, some pilots on the Red Sea employed triangular instruments of tin and quadrants whereby they recorded the altitude of the sun and the star which they particularly needed for navigation, whereas he and the sailors of Cambaya and all of India recorded their distance [according to angles] with a different instrument, not with those, because their navigation was dependent both on specific stars from north to south and also on other large stars which pass across the firmament from east to west. He showed this instrument to him at once, and it consisted of three plates."[1] This instrument, which became known among the Portuguese by the name of balestilha, was called ḫašabāt or also ḫaṭabāt by the navigators in the Indian Ocean[2] (see above, p. 42).

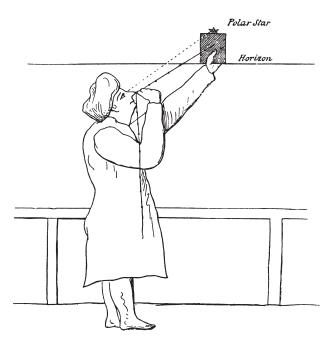



Illustration of the use of the instrument
(after H. Congreve, *A Brief Notice*, p. 230).

[1] F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 11, p. 227.
[2] ibid, p. 230.

Jacob's Staff

Our model:
Reconstruction of an instrument designed by Ya'qūb b. Isḥāq al-Kindī (d. shortly after 256/870).
Wood; sights, hinge and plummet of brass.
Length: 50 cm.
(Inventory No. A 4.23))

According to our present knowledge of the history of astronomy and nautical instruments in the Arabic-Islamic world, the common notion that the Jacob's staff was an invention of Levi ben Gerson or Johannes Regiomontanus proves to be untenable.[1] Not without being influenced by the Greeks, by the 3rd/9th century the Arabs were using, inter alia an instrument for establishing the heights of celestial bodies which was called *ḏāt aš-šuʿbatain* ("That one with the two arms"). The assumption may be correct that this instrument, in the course of time, was superseded in the Islamic world by the further development of the astrolabe and the invention of new instruments for the observation of the altitude of heavenly bodies from the mainland, and that it gained greater importance on board pitching and rolling ships for determining pole altitudes in seafaring. In this connection it is of special interest to see that Regiomontanus measured the diameter of the great comet appearing in 1472 with the help of a Jacob's staff whose cross-piece was divided into 210 units. Regiomontanus appears to have heard of this division of the circle, which we know from the navigators in the Indian Ocean, before the Portuguese expeditions.[2] Knowledge of this instrument, which was preferred by the navigators in the Indian Ocean, apparently reached Europe through travellers to Asia as early as the 7th/13th century. This instrument had earlier been called *ḫašabāt* ("boards") in the Arabic-speaking world, and was later known as *balestilha* in Europe.[3]

"The arms move around an axis, and along these arms the navigator sights the two objects whose angular distance he wants to define. Then, with the help of a thread, the distance between the free ends of the arms is measured, which is double the sine of half the angle."[4]

[1] For the discussion of the question and the literature, v. F. Sezgin, *Qaḍīyat iktišāf al-āla ar-raṣadīya* "*ʿaṣā Yaʿqūb*", in: Zeitschrift für Geschichte der arabisch-islamischen Wissenschaften (Frankfurt) 2/1985/Arabic part 7-30.

[2] v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 11, pp. 303-304.

[3] v. F. Sezgin, op. cit., vol. 12, pp. 227-232, 302-306; idem, *Qaḍīyat iktišāf al-āla ar-raṣadīya*, op. cit.

[4] Eilhard Wiedemann (with the collaboration of Th. W. Juynboll), *Avicennas Schrift über ein von ihm ersonnenes Beobachtungsinstrument*, in: Acta orientalia (Leiden) 5/1926/81-167, esp. pp. 137-138 (reprint in: Islamic Mathematics and Astronomy, vol. 92, Frankfurt 1998, pp. 137-223, esp. pp. 193-194, and in: E. Wiedemann, *Gesammelte Schriften*, vol. 2, pp. 1110-1203, esp. pp. 1173-1174); E. Wiedemann, *Über eine astronomische Schrift von al-Kindî* (Beiträge zur Geschichte der Naturwissenschaften XXI,1), in: Sitzungsberichte der physikal isch-medizinischen Sozietät (Erlangen) 42/1910/294-300 (reprint in: Aufsätze zur arabischen Wissenschaftsgeschichte, vol. 1, pp. 660-666).

Jacob's Staff

Our model: Wood, length: 50 cm.
Four cross-pieces for sighting that can be moved along the staff. Division into degrees on the staff.
(Inventory No. A 4.22)

Fig. from *Instrumentos de navegación: Del Mediterráneo al Pacífico*, Barcelona n.d., p. 68.

Another
Jacob's Staff

Another Jacob's Staff
This form is characterised by several cross-pieces of plum wood.
Our model is based on specimens (*ballestilla*) at the Museo Naval in Madrid[1] and the Museu Marítim in Barcelona.[2]

Our model: Hardwood, incised.
Longitudinal staff with four scales of angles, length: 73 cm.
Four sliding cross-pieces for sighting (48, 34, 26 and 18 cm).
(Inventory No. C 2.06

[1] v. *Astronomical Instruments in Medieval Spain*, Santa Cruz de la Palma 1985, pp. 114-115.
[2] v. *La navegació en els velers de la carrera d'Amèrica*, Barcelona, n. d., no. 52.

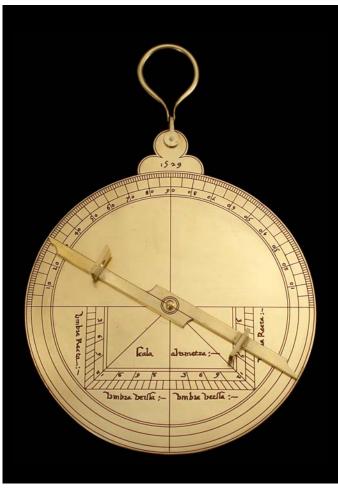
Our Model:
Hardwood, length: 72 cm.
Adjustable diopter sights
on both arcs.
Fixed slit sight at the centre
of the two arcs.
(Inventory No. C 2.07)

Davis Quadrant

In the further development of observation using the Jacob's staff, after the simplest form of the cross-piece (*backstaff*), the one by John Davis (ca. 1607) with cross-pieces on both sides, which was called Davis Quadrant after him, or also English Quadrant, proved to be particularly practical.
Here, standing with the sun at one's back, the navigator sights the horizon across the larger arc of the circle in such a way that the light entering through the smaller arc is exactly in line with the horizon. By the addition of the angular measurements to be read off on the two arcs the user elicits the angle of altitude of the heavenly body concerned.[1]
Our model is based on specimens in the Museo Naval, Madrid,[2] and in the Museu Marítim, Barcelona.[3]

Figura do QUADRANTE.

Sketch from A. Wakeley: *A Agulha de marear rectificada*, London 1762. *(The mariner's compass rectified,* London, 1763.)

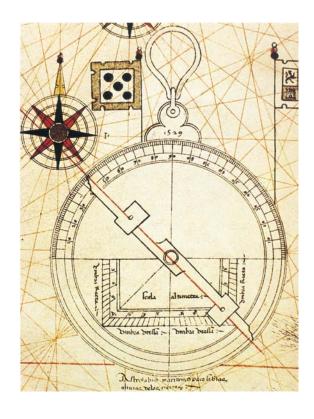
[1] v. Fr. Schmidt, *Geschichte der geodätischen Instrumente*, pp. 347-348, table XXII.
[2] v. *Instrumentos de navegación: Del Mediterráneo al Pacífico*, Barcelona, n. d. pp. 92-93.
[3] v. *La navegació en els velers de la carrera d'Amèrica*, op. cit., no. 53.

Marine Astrolabe

of Vasco da Gama

According to the Portuguese historian João de Barros[1] (1552), Vasco da Gama had a wooden astrolabe on board his ship during his first expedition. It was suspended "in the manner of a crane" from three poles and had a diameter of 3 *palmos* (= ca. 66 cm).

Our model:
Oak, diameter: 66 cm.
Tripod of maple wood, height: 150 cm.
Rotating alidade with diopter sights.
On the front are engraved two scales of 90° and the year.
(Inventory No. C 2.02)

[1] *Ásia*, Lisbon 1552, p. 280 (Dec. I, Livro IV, Cap. II, Ed. Lisbon 1946, p. 135), v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 11, p. 285.

Our model:
Brass, engraved.
Diameter: 18 cm. Rotating alidade with diopter sights.
Two scales of 90° serve for the measurement of altitudes; below these is engraved a scale for the hour-angle.
Made by Eduard Farré-Olivé (Barcelona).
(Inventory No. C 2.04)

Marine Astrolabe

of Diogo Ribeiro

The cartographer Diogo Ribeiro, who was in the service of Spain, depicted a marine astrolabe (*astrolabio náutico*) consisting of a single disc in his maps from the years 1525, 1527, and 1529.[1] Thus he was probably following the tradition of the astrolabe made by Ibn aṣ-Ṣaffār in Toledo in 420/1029 (see above, II, 95).

Fig. from D. Ribeiro, *Mapamundi* (1529).

[1] v. F. Sezgin, op. cit., vol. 11, pp. 298-299; cf. *Instrumentos de navegación: Del Mediterráneo al Pacífico*, Barcelona, n. d., p. 57.

Marine Astrolabe

Based on a Portuguese specimen from the 16th century and made by Martin Brunold, Abtwil, Switzerland

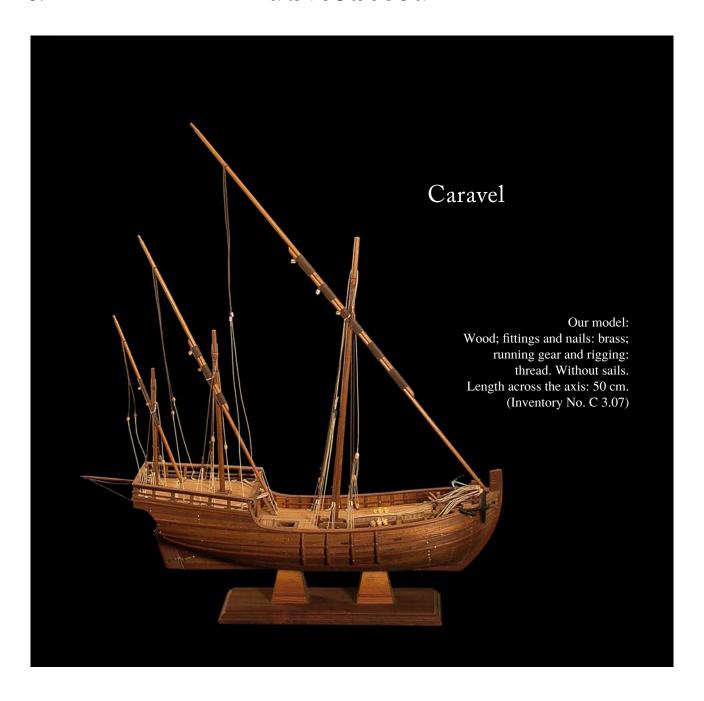
Our model:
Brass, engraved.
Diameter: 20 cm.
Rotating alidade with diopter sights.
On the front are engraved two scales of 90° and the year 1555.
(Inventory No. C 2.01)

Nautical Quadrant

This quadrant for determining the position at sea was also depicted by the cartographer Diogo Ribeiro on his three world maps from 1525, 1527 and 1529.

Our model:
Brass, engraved.
Radius: 15 cm.
Diopter sights on the side.
Scale for measuring altitudes,
below it a scale for the hours
before and after noon.
Projection of the 12 signs of the zodiac
above the 90° angle mark.
Made by Eduard Farré-Olivé (Barcelona).
(Inventory No. C 2.05)

Simple Hourglass

Our Model:
Mouth-blown glass in a wooden frame.
Height: 26 cm.
(Inventory No. C 2.09)

Replica of a sandglass as used for navigation. There were log-glasses with short duration for determining the vessel's speed, and also hour-glasses which emptied in the course of one watch (1 glass, ca. 2 hours).

Fourfold Sandglass

Our Model:
Mouth-blown glass.
Wooden frame.
Height: 26 cm.
(Inventory No. C 2.10)

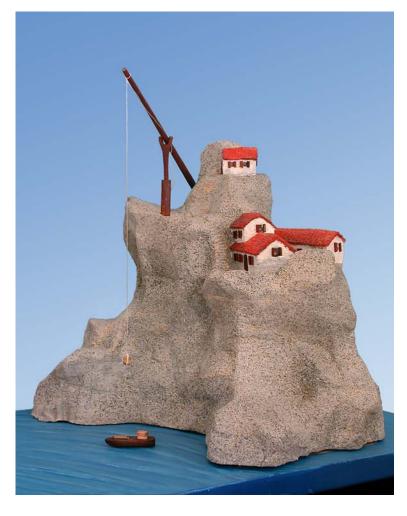
Since time measurement for navigational purposes must be very precise, chronometers were taken as sets on board until quite recently. In this way errors could be detected.

Caravel

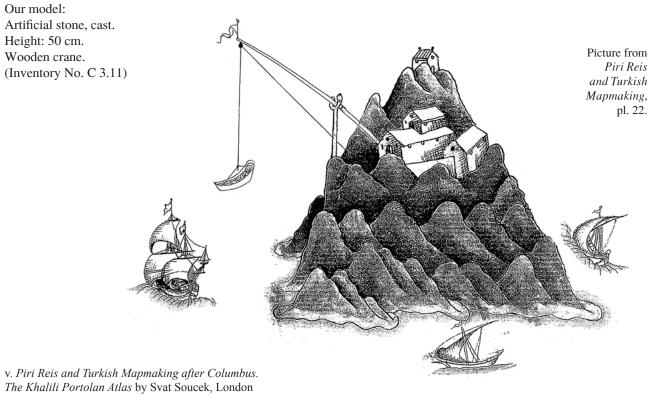
Our model:
Wood; fittings and nails: brass;
running gear and rigging:
thread. Without sails.
Length across the axis: 50 cm.
(Inventory No. C 3.07)

The caravel was one of the most important types of ships of the 9th/15th c. It probably developed from Maghribi vessels used by coastal fishermen. The rig fixed with 'lateen' sails (attested since the 2nd/9th c.) permits manoeuvring more forcefully against the wind than spar-rigging—it is one of the important steps forward in the history of seafaring—and probably reached western Europe via the Arabs.

Cf. B. Landström, *Segelschiffe*, Gütersloh 1970, pp. 100 ff.; T. Tryckare (Ed.), *Seefahrt*, Bielefeld 1963; P. Paris, *Voile latine? Voile arabe? Voile mystérieuse*, in: Hespéris (Paris) 36/1949/69-96.

Our model:
Wood, fittings and nails: brass;
rigging: thread. Without sails.
Length across the axis: 143 cm
(Inventory No. C 3.02)

dāw

(Dhow)

For this kind of vessel, which dominated the sea-trade in the Indian Ocean for centuries, the ‘lateen’ rig is, inter alia, characteristic, as well as the elastic joining of the planks of the hull with linen.

Gift of the Minister for Religious Affairs and Endowments of the Sultanate of Oman, Mr. ʾAbdallāh b. Muḥammad as-Sālimī.

Crane
for Lifting a Boat

The picture reproduces a representation from the atlas of the Turkish admiral Pīrī Reʾīs (ca. 1525). An island in the Sea of Marmara with a monastery is shown, to which a boat is being lifted by means of a crane.[1]

Our model:
Artificial stone, cast.
Height: 50 cm.
Wooden crane.
(Inventory No. C 3.11)

Picture from *Piri Reis and Turkish Mapmaking*, pl. 22.

v. *Piri Reis and Turkish Mapmaking after Columbus. The Khalili Portolan Atlas* by Svat Soucek, London 1996 (= Studies in the Khalili Collection, vol. 2), plate

COMPASSES

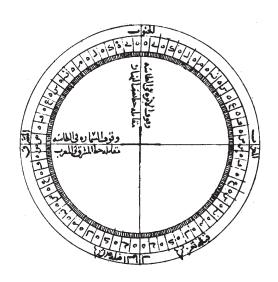
Fish Compass

It appears that the common compass needle known in the Arabic-Islamic world had either the form of a magnetised fish or consisted of another magnetised object. This was placed into a receptacle filled with water and adjusted itself in a north-south direction. The basic principle of such a compass is demonstrated by this model.[1]

Our model:
Brass receptacle, gilded.
Diameter: 21 cm.
Wooden fish with a core of magnetised iron, length: 8 cm.
(Inventory No. C 1.01)

[1] v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 11, p. 240 ff.

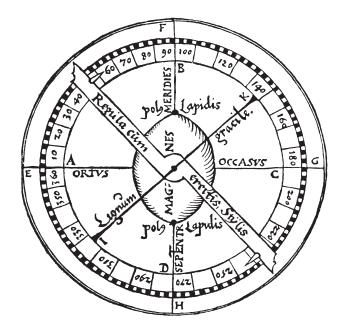
Floating Compass
of al-Malik al-Ašraf

Gilded receptacle.
Diameter: 16 cm.
Scale: 360 degrees.
Iron needle: 9 cm, affixed at right angles under the wooden float.
(Inventory No. C 1.04)

From al-Malik al-Ašraf (wrote ca. 690/1291), the ruler of Yemen, who took an interest in astronomy, medicine and genealogy (see above, II, 105), a treatise survives that contains a description of the compass. In this treatise, entitled Risālat aṭ-Ṭāsa, he describes a floating compass, which shows quite a sophisticated stage of development.

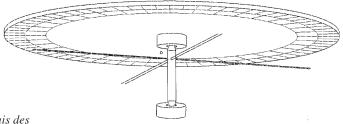
In a circular receptacle filled with water a light pin, made of fig-tree wood and impregnated with wax or pitch, supports the magnetic needle in such a way that both are connected to each other in the middle in the shape of a cross. The surface rim of the receptacle is divided into 4 × 90°, where every fifth degree is emphasised by a line (72 in all).

Al-Malik al-Ašraf also tried to transfer the solution of the azimuth calculation of the astrolabe to the compass designed in this manner. We shall encounter something similar to this in the needle compass of Peregrinus (infra, p. 60).[1]

Our replica is based on the description and the drawing by the author.

[1] v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 11, p. 247.

Floating Compass
of Peregrinus

Our model:
Circular box
(cork, acryl, copper),
diameter: 15 cm.
Alidade with shadow pins,
rotating. Scale: 4 × 90°.
(Inventory No. C 1.05)

Around 1270, in a letter addressed to his friend Syger de Foucaucourt, the French scholar Petrus Peregrinus de Maricourt describes two types of compasses. It is worthy of note that he wrote this letter from the city of Lucera in Lower Italy which Frederick II had settled with Arabs. One of the two types of compasses which he describes is "equipped with a magnetite rather than a needle. The former is whetted into a round shape and enclosed in a round, watertight box. On the lid of the box four quadrants with 90 divisions each are marked out. In order to find North, the box is placed in a bowl of water, across which a thread is stretched in the direction of the meridian. As soon as the index plate is marked out, a pointer is placed on top which can rotate around the centre of the circle and has two upright pins. Now the box can be put inside any kind of water and it is only necessary to aim at a star or the sun by aligning the pins at the ends of the pointer (so that, for example, in the case of the sun the shadow of one pin falls along the line of the pointer) in order to elicit the current divergence of the star or sun from the meridian and thus the time of day or night."[1]

[1] H. Balmer, *Beiträge zur Geschichte der Erkenntnis des Erdmagnetismus*, Aarau 1956, p. 61; cf. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 11, pp. 244–245.

Needle Compass
of Peregrinus

The second compass described by Petrus Peregrinus has a magnetic needle “which is inserted into a little hole in the middle of a vertical axis, while the axis turns in its bearings between the base and the glass cover of a round box.”[1] This means that Peregrinus is not yet familiar with the seemingly quite modern construction which we can trace in the Arabic-Islamic world at the latest by the 15th century and in which the magnetic needle is placed on a pin with a small cap.[2] Like al-Malik al-Ašraf (see above, p. 58), Peregrinus transfers the problem of azimuth calculation from the astrolabe to the compass by means of a pointer.

Our model:
Wooden cylinder with
fitted, inscribed glass disc,
diameter: 10 cm.
Cross of iron needles,
suspended between two brass pins on
the inside so that it can rotate.
Pointer with shadow pins, attached to
the disc so that it can rotate.
(Inventory No. C 1.06)

[1] H. Balmer, *Beiträge zur Geschichte der Erkenntnis des Erdmagnetismus*, p. 51; cf. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 11, p. 242.
[2] F. Sezgin, op. cit., vol. 11, p. 242.

Our model:
Hardwood cylinder,
diameter: 15 cm.
Glass lid held tight with a copper ring.
Magnetised iron needle, movable on a brass spike.
(Inventory No. C 1.02)

One of the Four Types of

Compass

used by the navigatorrs in the Indian Ocean

The Portuguese historian Hieronimus Osorius (1506-1580) describes with remarkable precision three types of compass, with which Portuguese seafarers became acquainted in their encounters with the navigators of the Indian Ocean. Even the first type appears to be quite modern. It consists of a needle placed on a pin in a circular case which is closed with a glass lid. In the words of Osorius:[1]

"When sailing they used navigational instruments (*normae navicularae*), which the sailors call 'needles' (*acus*). Their shape is unfamiliar to those who live far from the maritime regions [and therefore] I would like to explain what is unfamiliar. It is a flat and round container made of wood, two or three fingers high. In the middle is a pin which is sharpened at the top and is somewhat shorter than the height of the container. On this a *regula* is placed, which is most carefully made of iron, delicate and narrow and cut [in such a way] that it does not exceed the length of the diameter of the container. The point of the pin goes through the middle of the *regula*, which is concave underneath and bulges upwards. [The *regula*] is suspended in equilibrium in such a way that on both sides [of the pin] equal [right] angles are formed. The whole thing is covered by a glass lid which is surrounded by a ring of copper wire so that the *regula* can neither 'dance' nor incline to one side."

[1] *De rebus Emmanuelis libri XII*, Köln 1574, Liber I, p. 27; v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 11, pp. 253–254.

A More advanced Type of Compass from the Indian Ocean

Our model:
Wooden cylinder
in a glass container,
diameter: 16 cm.
Glass lid with
engraved brass ring.
Inscribed cardboard disc.
Below it an iron wire,
bent in the form of a fish,
rotating on a vertical
pin of brass.
(Inventory No. C 1.03)

The second type of compass described by the Portuguese historian Osorius, with which Vasco da Gama and other western seafarers became acquainted through their colleagues who were at home in the Indian Ocean, was the result of a further development:[1]

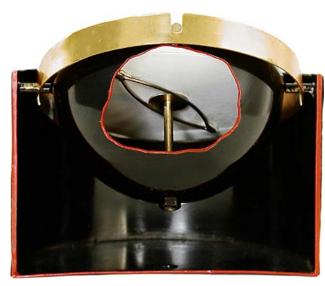
"So that it would become even simpler, and because human ingenuity always invents something in addition to what already exists, they thought up another kind of instrument, with which they were able to maintain their course even more exactly. From iron wire they make a figure with equal sides but unequal angles, in the shape of a deformed rhombus. On this they stick a circular piece of cardboard (*carta*), one from the top and one from the bottom. With the added strength of the magnet they set the figure up so that one of the acute angles points to the North and the other to the South, and one of the obtuse angles to the East and the other to the West. The length of the diameter of this disk (*orbis*) does not exceed the length of the [rhombic] figure. The disk then has a copper hollow in its centre which is made in the same way as we described it in the centre of the *regula*. The point of the pin is inserted into the hollow and thereby keeps the disk suspended, which not only works like the regula we have already described but also optically shows the directions of all the winds which move the ships, since on the top piece of cardboard North, South, East, West and the directions in between are marked (*describuntur*) most precisely."

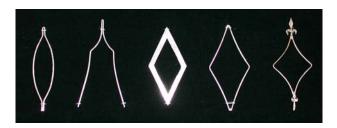
The cardboard disc is marked with 32 points of direction at intervals of 11°25' which indicate the approximate rising and setting of 15 fixed stars and the two poles.

[1] v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 11, p. 255.

Compass

suspended after the system which as subsequently and without justification called ‹cardanic›

Our model:
Hardwood cylinder,
diameter: 24 cm,
height: 18 cm.
Hemispherical compass box,
“Cardanic” suspension by
means of a copper ring.
Cardboard disc with “iron-fish”,
rotating on a pin, tightly closed
from above with a glass disc.
(Inventory No. C 1.07)

About the third and highest stage of development of the compass which the Portuguese seafarers became familiar with in the Indian Ocean the historian H. Osorius (1506-1580) informs us as follows: “When the instrument is set up like this, there remains the disruptive factor that the ship in a swell rolls towards the bow and the stern or lists to one of the two sides, so that it (the disk) drops and blocks and can no longer indicate the North by moving freely. So that this no longer happens, people have thought up something extremely astute: the container (vas) itself is tightly surrounded with a copper ring just below the top edge. On both sides of this ring a steel rod (?*virgula calybea ducta*) is inserted into the opening of another larger outer ring at a suitable distance. Both rods are the same and stand opposite each other so straight that, if they were joined to form one single rod, this rod would correspond to the diameter of the ring-shaped space between the rings. The outer ring can be rotated around these two rods as if round an axis. Again, two equal rods go equidistant from this outer circle to a round basin surrounding them (*alveolus orbiculatus*), which contains everything. The outer rods are placed in relation to the inner ones such that if they were made to approach each other they would bisect each other at right angles. Although the whole instrument is made of copper underneath and is heavy, it does not bump into anything. It is impelled on all sides to remain in the centre. And since it is suspended and is mobile and thus keeps its equilibrium, it always shows the direction exactly, even in rough seas. Thus it is that there is nothing which can interfere with this instrument in showing North.” [1]

[1] v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 11, pp. 255–256.

The new element consisted therefore in the ingenious idea of the “Cardanic” suspension which helps to keep the compass disc balanced in a horizontal position during the ship’s voyage.[1]

The magnetised metal loop, which is fixed under the disc, positions the disc in the north-south direction. Through the “Cardanic” suspension, the point of the compass can also be measured while heeling over (sloping position). The disc carries the names of the 15 fixed stars with their rising and setting at intervals of 11°15'. It is also divided into degrees.

Model for demonstration belonging to it, open on one side: brass, diameter: 12.5 cm.

A. Breusing, *Zur Geschichte der Geographie. 1. Flavio Gioja und der Schiffskompass*, in: Zeitschrift der Gesellschaft für Erdkunde zu Berlin 4/1869/31–51, esp. p. 47 (reprint in: Acta Cartographica, Amsterdam, 12/1971/14–34, esp. p. 30). Breusing refers to Cardano’s book *De subtilitate*, book XVII: *De artibus artificiosisque rebus.*

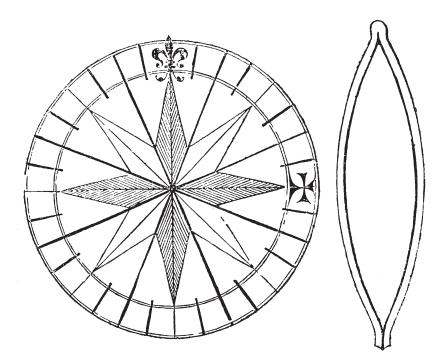
Various compass needles. They were fixed under the cardboard disc and, after being magnetised with a lodestone, showed the north-south direction. The “fish shape” (on the left) was the most common among the Arabs.

[1] Arthur Breusing cautions against the habit of calling this invention “Cardanic”: “However, Cardanus himself says: ‘A method of setting up the emperor’s chair was invented so that, while travelling, he always sits without moving and comfortably, despite all oscillations. This is done by a special combination of rings. Because when three movable rings are connected to each other in such a way that the pivots of the one are on the top and below, those of the other on the right and the left, and those of the third in front and behind, then such an arrangement must remain completely at rest with each position of the travelling coach, since every movement follows from three axes at the most. The principle is derived from those lamps which will not spill the oil, whichever way they are held.’ From this at least this much follows that Cardanus cannot be considered the inventor of the arrangement, and that it is therefore named after him only because it was probably mentioned by him first. Despite all my investigations I did not succeed in ascertaining anything more about the origin of this so ingenious invention.”

Compass
of the Navigator Ibn Māǧid

It seems to be a great merit of Ibn Māǧid, one of the greatest navigators of the region, to have constructed the highest stage of the compass developed in the Indian Ocean. In his book *Kitāb al-Fawāʾid*, written in 895/1489, he states that it was one of his inventions in the science of navigation to put the magnetic needle directly on the compass. Taking into consideration the shapes of the compass in the Indian Ocean known to us, where a magnetic wire or a magnetic needle rotates freely on a pin, either below a round cardboard disc or without the cardboard disc, we can probably understand the invention of Ibn Māǧid as meaning that he let the magnetic needle rotate freely above the cardboard disc on the pin.[1]

Our model:
Hardwood cylinder.
Diameter: 16 cm.
Height: 10 cm.
"Cardanic" suspension
by means of a copper ring.
Iron needle, length: 8 cm,
on a pin in the hemispherical case,
the latter closed with a glass disc.
(Inventory No. C 1.08)

[1] v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 11, p. 261.

A Device as an Additional
Attachment to the Compass

Our model:
Brass, etched, on wood.
Length of the side 41 cm.
Thickness: 6 mm.
(Inventory No. C 1.23)

From the statements of the two great navigators Ibn Māǧid and Sulaimān al-Mahrī it can be deduced that the cylinder-shaped compass was combined with a supplementary device during voyages in the Indian Ocean: surrounding the cylinder there was a plate which was inscribed with the 32 converging lines of the points of direction and the names of the rising and setting of the 15 known fixed stars, besides the two poles. The plate with the compass had its fixed place on the forecastle (*ṣadr al-markab*). It enabled the navigator to read off the angle of direction that was changing during the voyage.[1]

[1] v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 11, p. 260.

One Compass Type Used by Columbus[1]

It is quite probable that Christopher Columbus used the second of the three types of compasses mentioned above (p. 62) which the historian Osorius (1506-1580) described. Its characteristic is that a magnetised wire loop was pasted on a piece of paper from below against the compass disc. The disc itself is balanced in such a way that it can move freely on the tip of a pin. The Spaniard Martin Cortés describes in his *Breve compendio de la sphera y de la arte de navegar* (Sevilla 1551, p. 80) such a compass and supplies his description with a drawing of the compass disc and the wire loop.[2]

Apparently Italian navigators came to know of this type of compass used in the Indian Ocean as early as the 9th/15th century. This impression is particularly strengthened by the report on the first itinerary of Vasco da Gama, where it is said that he had seen how the seafarers of the Indian Ocean used magnetic needles after the manner of the Genoese.[3] Unfortunately, it has not been noticed so far that the division of the disc into 32 parts does not represent the lines of direction of the compass card, but has a connection to the compass disc of the navigators of the Indian Ocean, whose division has its origin in the points of direction of the rising and setting of the 15 known fixed stars and the two poles.

[1] Besides the "Genoese" type, described here, during his voyages he also used compasses which he called "Flemish". This type was also constructed according to the principle that the cardboard disc moved together with the wire loop. From Columbus' statements we can deduce that the "Flemish" type of the compass also had a disc similar to the "Genoese" type, cf. H. Balmer, *Beiträge zur Geschichte der Erkenntnis des Erdmagnetismus*, Aarau 1956, pp. 80–84.

[2] v. H. Balmer, *Beiträge*, op. cit., pp. 79–80.

[3] v. *Roteiro da primeira viagem de Vasco da Gama* (1497–1499) por Álvaro Velho, préfacio, notas e anexos por A. Fontoura da Costa, Lisbon 1940, 2nd ed. 1960, p. 23; cf. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 11, p. 307.

The First ‹True Ship's Compass› in Europe

Heinz Balmer, to whom we are indebted for a valuable work on the history of the discovery of geomagnetism, refers to a type of compass as the "true ship's compass"[1]; in fact, this type is quite simply the one described by the Portuguese historian Osorius as the third type of compass used by Arab navigators in the Indian Ocean (see above, p. 63):
"The needle, endowed with a small cap and balancing freely, rests on the tip of a pin firmly mounted at the bottom of the case. On the upper side of the needle a round disc is affixed and on it a partial circle is drawn which turns with it as a movable horizon. This disc is not divided into 360 degrees, but in wind markings of 11 1/4 degrees each. Lastly, so that the small case always remains horizontal, it is suspended from two intersecting axes in two horizontal rings, so that it can turn around one axis in the inner ring and the inner ring can turn in the outer ring around the other axis, which lies at right angles to the first one. Then this little box can always move towards the position of its centre of gravity, despite the pitching and rolling of the ship."
Balmer continues: "The Spaniard Pedro de Medina speaks in 1545 and the Dutchman Stevin in 1599 about this compass as something that was quite common. The suspension in the two rings, it is true, is said to have been invented only by Cardano, who lived from 1501 to 1576. But nobody tells us who was the first to attach the needle under a cardboard with the compass card and thus placed it upon a pin."

Our model:
Turned cylinder of hardwood.
Diameter: 24.5 cm. Height: 17 cm.
"Cardanic" suspension by means of a copper ring.
Disc with an iron wire, bent in the shape of a fish, between two pointed tips, mounted in the hemispherical compass case so that it can rotate.
(Inventory No. C 1.09)

It is a pity that Balmer did not have any knowledge about the Arab navigation in the Indian Ocean and about Osorius' descriptions of the types of compasses found there.
The assumption may not be unfounded that the "true ship's compass" as well as the two other types of compasses described by Osorius reached Portugal from the Indian Ocean even with the first Portuguese expeditions. The first "true ship's compass" to make its appearance in Europe probably looked like the model illustrated here.

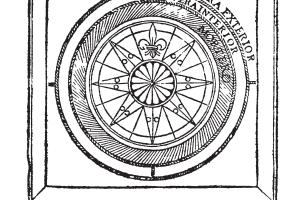
[1] v. H. Balmer, *Beiträge*, op. cit., p. 69.

Our model:
Hardwood cylinder.
Diameter: 26 cm.
Height: 20 cm.
(Inventory No. C 1.10)

One more model of the
‹Ship's Compass›

After Georges Fournier, *Hydrographie contenant la théorie et la practique de toutes les parties de la navigation*, Paris 1643.

Ship's Compass
in a Square Housing

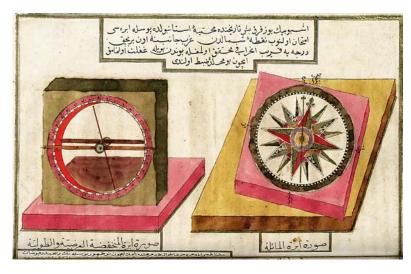
Our model:
Hardwood case: 20 × 20 × 10 cm.
Wooden cylindrical compass case.
"Cardanic" suspension on a brass ring.
Disc with an iron wire bent in a rhombus shape,
placed upon a brass pin so that it can rotate.
(Inventory No. C 1.11)

Reconstruction based on the shape described by Rodrigo Zamorano (1581).[1] The housing supporting the compass case with its "Cardanic" suspension is, for the first time, square.

CAXA QVADRADA
ESFERA EXTERIOR
ESFERA INTERIOR

[1] Rodrigo Çamorano, *Compendio de la arte de navegar,* Sevilla 1581, reprint Madrid 1973, fol. 36aa.

Two Ottoman Types of Compasses

Our models:
a) Wooden frame (base 25 × 25 cm), foldable; scale and alidade of brass, magnetic needle between acrylic panes. (Inventory No. C 1.24)
b) Hardwood case: 25 × 25 × 15 cm. “Cardanic” suspension on a brass ring. (Inventory No. C 1.12)

To the first Müteferriqa (1145/1732) edition of the Ottoman-Turkish book *Ǧihānnumā* by Ḥāǧǧī Ḫalīfa (1609-1658) was added the picture of a compass (between pp. 65 and 66, on the right), in which the magnetic needle as a wire loop does not carry the cardboard disc, being balanced as a magnetised pointer on a pin above the disc. Thus it recalls the type of compass which was described by the navigator of the Indian Ocean, Ibn Māǧid, as his own invention (see above, p. 65).
A note in the text explains that in 1145/1732 a deviation of 11°30' was observed for Istanbul, which is also demonstrated by the compass.
The other compass described by Ḥāǧǧī Ḫalīfa and shown in the illustration on the left is a multiple instrument; when opened and set up vertically, an alidade serves to measure the altitude of heavenly bodies; when folded together into a horizontal position, a magnetic needle mounted between two glass panes can be used as a compass.

Our model:
Plywood box,
30 × 30 × 15 cm.
“Cardanic” suspension
on a square brass ring.
Hemispherical compass
case, surrounded by a square
device for direction finding.
Rhombus-shaped iron wire
beneath the cardboard disc.
Disc with a division into 32
parts.
(Inventory No. C 1.13)

Ship’s Compass

Reconstruction of a European compass from the 18th century with roughly calibrated disc and relatively precise device for direction finding. After Nicholas Bión, *Traité de la construction et des principaux usages des instruments de mathématique*, Paris 1752, p. 278, fig. 2 (v. on the right).

Fig. from N. Bión, *Traité ...* , op. cit., p. 278, fig. 2, after *Instrumentos de navegación del Mediterranéo al Pacifico,* Barcelone, n.d., p. 88.

Ship's Compass

Replica of a compass from the 19th century. The so-called wind markings are replaced here by the points of the compass.

(Original in the Museu Marítim, Barcelona, v. *La navegació en els velers de la carrera d'Amèrica*, Barcelona: Museu Marítim n. d., no. 47)

Our model:
Hardwood box,
21 × 21 × 13.5 cm.
Groove for inserting a lid.
Cylindrical compass case of brass,
diameter: 14 cm.
"Cardanic" suspension on a brass ring.
Rhombus-shaped iron wire under the cardboard disc. On the disc "compass card" with 32 divisions, on the rim division into 4 × 90°.
Inscription in the middle of the disc: "Antigua casa / Rosell / Barcelona".
(Inventory No. C 1.14)

Ship's Compass

Based on a Spanish compass from the 19th century. The original was apparently inserted into some device on the ship: the "Cardanic" ring is connected with the case only on its inside, towards the outside pins are protruding.

(Original in the Museu Marítim, Barcelona, v. *La navegació en els velers de la carrera d'Amèrica*, Barcelona: Museu Marítim n. d., no. 45)

Our model:
Brass case, diameter: 22 cm.
"Cardanic" suspension on a brass ring.
Rhombus-shaped iron wire beneath the cardboard disc.
Disc with 32 divisions according to the points of the compass and with markings in degrees (4 × 90°), inscription: "Escuela Nautica Masnou".
(Inventory No. C 1.15)

Our model:
Brass, gilded.
Diameter: 18 cm.
The cardboard disc is mounted between two spikes so that it can rotate. On its reverse the iron wire in the form of a rhombus is affixed. On the disc markings in degrees (4 × 90°), and a compass card with 32 divisions, protected by a glass inserted into the crown.
(Inventory No. C 1.16)

Ship's Compass

Based on the original of a Portuguese compass of the 18th century in the form of a crown. The "Cardanic" suspension is not necessary here, because the compass with the disc turned downward is attached to a thread. Minor pitching and rolling by the ship was thus compensated for. The compass was suspended with the needle downwards above the captain's bed so that he could also follow the course from there.

(Original in the Musée de la Marine, Paris)

'The Mining Surveyor'
Compass

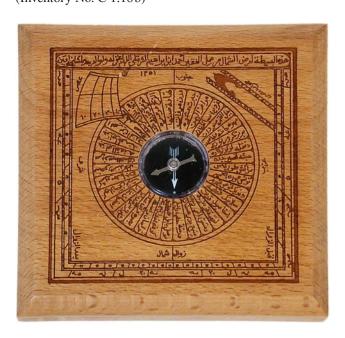
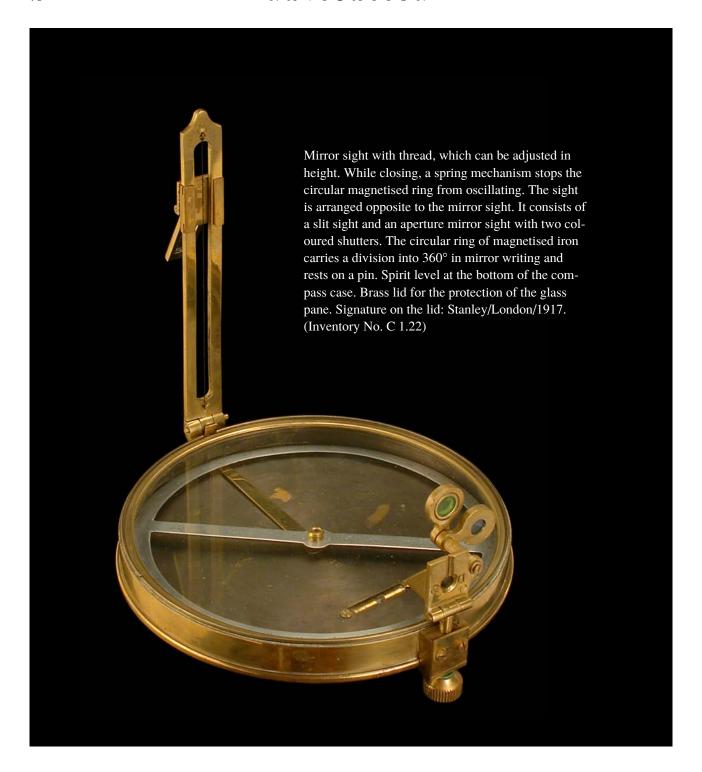
Chinese land surveyor compass with sundial from the year 1765/66 from the Institute's collection.

Hardwood, incised.
Diameter: 115 mm.

Upper half of the instrument, inner side: compass needle with detailed azimuth scale.

Lower half of the instrument, inner side: gnomon with adjustable disc of scales. Compass needle with rough azimuth scale.

Inscription on the front: "Sundial, made in the 30th year of the Ch'íen Lúng era" (1765/66). (Inventory No. C 1.17)

Prayer Compass

Replica of an Ottoman-Turkish compass of the 19th century in three finishes. The original is in the Rautenstrauch-Joest Museum für Völkerkunde in Cologne. It was made by a certain Aḥmad b. Ibrāhīm aš-Šarbatlī in 1251/1853.
The names and coordinates of some important cities of the Islamic world are inscribed in the area around the centre with the compass needle. If the user is at one of those cities, he can determine the direction for prayer towards Mecca with the compass. With the help of the gnomon on the side indicated as the west, the times of prayers can be read off from the scale adjacent to it.

Our Model: Brass, etched.
16 × 16 × 2 cm.
(Inventory No. C 1.18c)

Our Model: Hardwood, incised, etched.
13 × 13 × 2 cm.
(Inventory No. C 1.18b)

Our Model: Silver, engraved.
11 × 11 × 2 cm.
(Inventory No. C 1.18a)

Mirror sight with thread, which can be adjusted in height. While closing, a spring mechanism stops the circular magnetised ring from oscillating. The sight is arranged opposite to the mirror sight. It consists of a slit sight and an aperture mirror sight with two coloured shutters. The circular ring of magnetised iron carries a division into 360° in mirror writing and rests on a pin. Spirit level at the bottom of the compass case. Brass lid for the protection of the glass pane. Signature on the lid: Stanley/London/1917. (Inventory No. C 1.22)

Compass for Surveying

An English compass of 1917, with direction finding and spirit level, from the Institute's collection. Through the slit sight the desired object is aligned until it is in line with the thread of the opposite visor. After the magnetised circular ring has stopped oscillating, the degree can be read off through the mirror of the aperture sight.

Fluid Ship's Compass

A European compass from the beginning of the 20th century from the Institute's collection. The residual deviation which depends on the course, is compensated for with the two hollow iron spheres as compensation magnets.

Compass case of brass,
"Cardanic" suspension; s
ealed with a disc,
floating in alcohol.
Diameter: 104 mm.
Disc with division into
360 degrees and points of the compass.
Two hollow iron spheres,
diameter: 40 mm, screwed on
in such a way that they can
be adjusted.
(Inventory No. C 1.19)

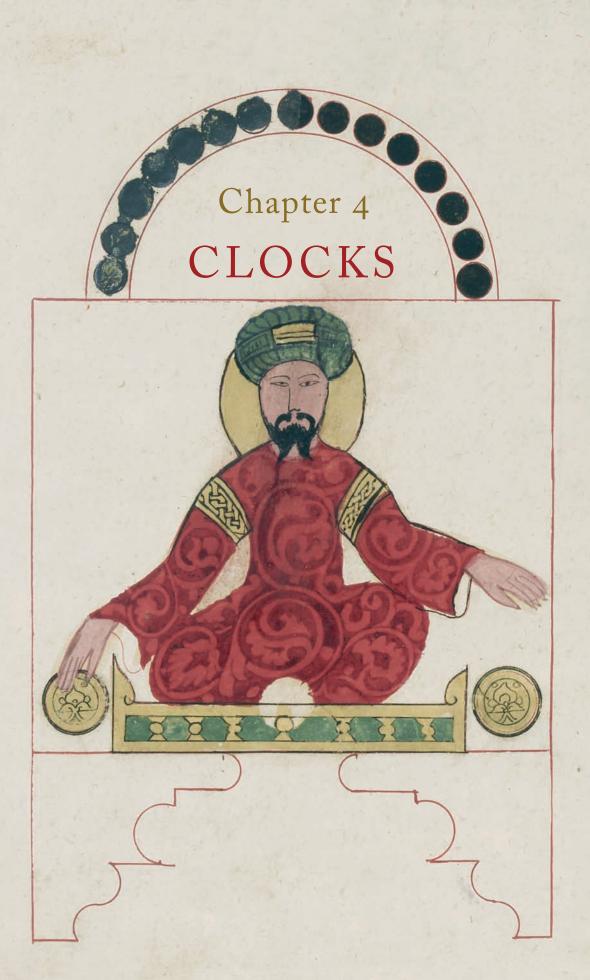
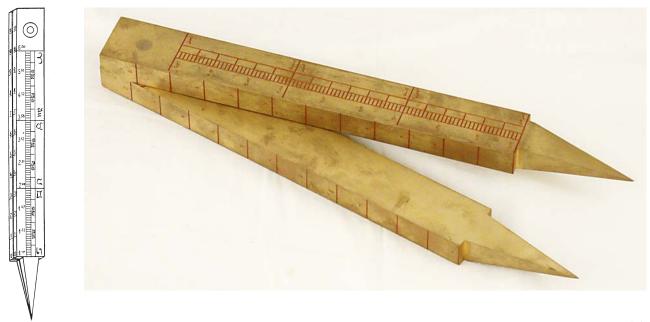
Compass

English ship's compass from around 1920, from the Institute's collection. Because of its modest size it was probably meant for a small yacht.

Compass case of brass,
diameter: 10 cm,
closed watertight with a
glass pane, can be screwed
to a brass lid, "Cardanic" suspension.
A 360° division, the points of the compass
and "T. Cooke / London"
are engraved on the bottom of the case.
The magnetic needle is mounted upon a pin.
(Inventory No. C 1.20)

Geographical Compass

An English compass with direction finding, from the 20th century, in the Institute's collection. Through the slit sight an object is aligned until it is in line with the wire in the lid. Since the disc swings rather slowly in the north-south direction, it can be supported with the spring mechanism. After alignment of the disc, the degree can be read off through the reflected aperture sight.

Compass case of brass with glass lid, diameter: 70 mm.
Small foot for mounting on a stand.
Lid with a hinge, foldable, with a mirror on the inside and furnished with a glass sight with a thin wire. Opposite slit sight, under it aperture mirror sight.
Compass disc of aluminium with a division into 360° in mirror writing and indication of the four points of the compass.
Magnetic needle fixed beneath the disc.
Spring mechanism on the side for manually stopping the disc from oscillating.
Below two set-screws for adjusting the disc.
(Inventory No. C 1.21)

Fluid Ship's Compass
with Hurricane Lantern

From the Institute's collection, probably early 20th century.

Magnetic compass with division into 360° and points of the compass, "Cardanic" suspension in cylindrical brass case (diameter 19 cm). On the side a device for lighting, container with a wick and a screw for adjusting, signed: Sherwoods Limited, Vaporite no. 1 (Inventory No. C 1.25).

Chapter 4

CLOCKS

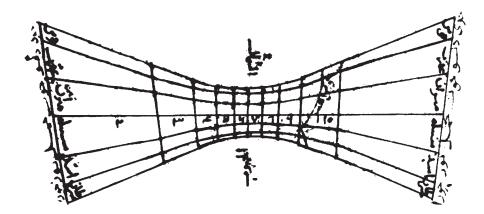
Our model:
Length of the arms: 27 cm.
Brass, engraved.
(Inventory No. B 2.08)

Compasses

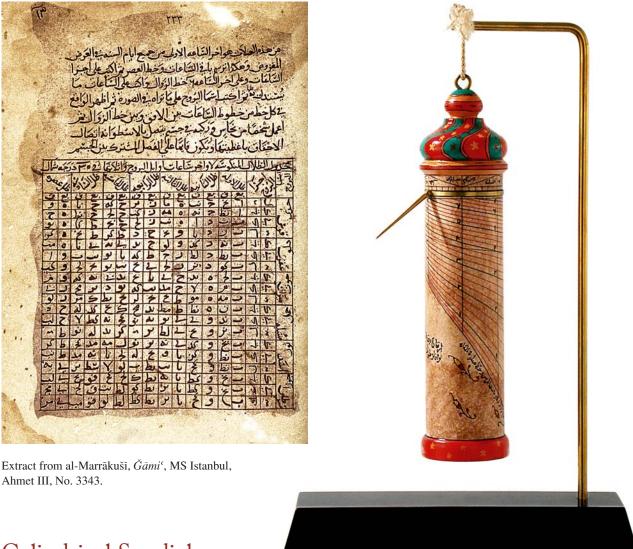
For Determining the Times of Prayer

In an as yet unpublished manuscript, written most probably by the well-known astronomer Abū ʿAbdallāh Muḥammad b. Mūsā al-Ḫwārizmī[1] (1st half of the 3rd/9th c.), a simple instrument is described which served to determine the times of prayers (*barkār yuʿrafu bihi l-auqāt li-ṣ-ṣalāt wa-yuqāsu bihi ẓ-ẓill*). The description was studied by J. Frank and E. Wiedemann.[2] Their summary runs as follows: "The instrument is a type of compasses, whose arms on their outer sides have a table showing the lengths of the shadow of the compasses when they have been set up vertically in the ground with the iron tips that are affixed at their free ends, at the time of observing the *ʿaṣr* [afternoon] prayer, for all positions of the sun in the zodiac. On the outer side of one of the arms the proportions of the values of the northern zodiac are marked, on that of the other those of the southern zodiac (see figure). The two other sides of the arms of the compasses have a scale in which the length of the compass arm (without the tip) is divided into 12 equal divisions (sometimes also into subdivisions). To determine the time of prayer, the folded compasses are pushed with the tips so deep into the ground that the beginning of the divisions of length coincides with the level of the ground. The endpoint of the shadow cast by the compasses is marked and the distance between it and the place where the compasses are pushed into the ground is measured by their length markings. For this purpose the compasses are stretched apart, since the shadow of one arm at the time of the *ʿaṣr* prayer is longer than the simple length of the arm. If the distance measured equals the value for the day, which can be derived from the table of the outer sides, then the time for prayer has begun. If this value has not yet been reached, the user must wait until this is the case."

[1] Active under Caliph al-Maʾmūn (r. 198/813-218/833, v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 6, pp. 140-143). The preserved manuscript (Berlin 5790, fol. 77b-97b) seems to be a part of his *Zīǧ* or of his *K. al-Asṭurlāb*.
[2] Die *Gebetszeiten im Islam*, in: Sitzungsberichte der Physikalisch–medizinischen Sozietät zu Erlangen 58/1925/1–32 (reprint in: Islamic Mathematics and Astronomy, vol. 92, Frankfurt 1998, pp. 97–128).

Chandelier clock
with Twelve Lamps

Our model:
Diameter: 80 cm.
Brass, gilded.
Height of the glass bottles: 18 cm.
(Inventory No. B 3.03)

Replica of a device described by the well-known astronomer ʿAlī b. ʿAbdarraḥmān b. Aḥmad Ibn Yūnis (d. 399/1009), who was active in Egypt; he called this device for time-measurement *ṯuraiyā* (lit. "Pleiades").
Each time an hour of the night has elapsed, one lamp goes out. The first lamp holds enough petroleum for one hour, the twelfth for twelve hours.
If all the lamps are lit simultaneously, the number of hours can be read off on the basis of whether they are extinguished. According to Ibn Yūnis the twelfth lamp should contain 36 *dirhams* of oil for the longest night of the year and 24 *dirhams* for the shortest night. The chandelier therefore indicates temporal, i.e. unequal hours.

Literature: E. S. Kennedy and W. Ukashah, *The Chandelier Clock of Ibn Yūnis*, in: Isis (Washington) 60/1969/543-545; F. Sezgin, Geschichte des arabischen Schrifttums, vol. 6, p. 231; E. Wiedemann and F. Hauser, *Über die Uhren im Bereich des islamischen Kultur*, in: Nova Acta. Abhandlungen der Kaiserlich Leopoldinisch-Carolinischen Deutschen Akademie der Naturforscher in Halle 100/1915/1-272, esp. p. 18 (reprint in: E. Wiedemann, *Gesammelte Schriften zur arabisch-islamischen Wissenschaftsgeschichte*, Frankfurt 1984, vol. 3, pp. 1211-1482, esp. p. 1228, and in: Natural Sciences in Islam, vol. 41, pp. 21-292, esp. p. 38).

Sundial
of al-Malik al-Ašraf

In his book *Muʿīn aṭ-ṭullāb ʿalā ʿamal al-aṣṭurlāb* the third sultan of the Rasulid dynasty in the Yemen, al-Malik al-Ašraf ʿUmar b. Yūsuf (ruled 694/1295-696/1296), offers a sketch of the sundial he designed for the latitude of Cairo.[1] Aside from this astronomical work, treatises by him in the fields of medicine and genealogy have also come down to us. His extant astrolabe (see above, II, 105) testifies to his great abilities as an instrument maker (see above, p. 58).

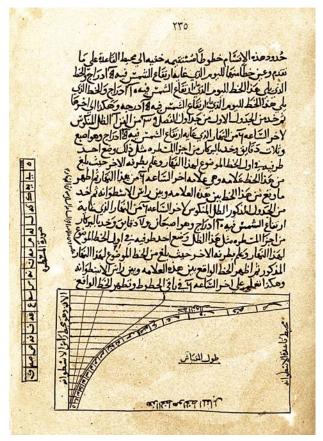
Our model:
Engraved brass plate: 36 × 46 cm,
with gnomon,
inlaid in a table of hardwood.
Foot of brass.
(Inventory No. B 2.03)

[1] After the Cairo manuscript, Dār al-Kutub, Taimūr, riyāḍīyāt 105, fol. 107b-138a, v. D. A. King, *A Survey of the Scientific Manuscripts in the Egyptian National Library*, Winony Lake (Indiana) 1986, pp. 209, 282. v. also C. Brockelmann, *Geschichte der arabischen Litteratur*, vol. 1, p. 494, 1st supplementary volume p. 904; Ziriklī, *Aʿlām*, vol. 5, p. 232.

Extract from al-Marrākušī, *Ǧāmiʿ*, MS Istanbul, Ahmet III, No. 3343.

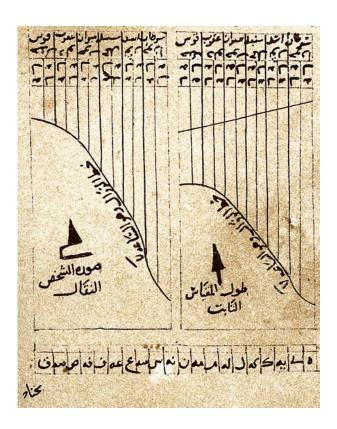
Cylindrical Sundial

Our model:
Height: 19 cm. Wood, lacquered.
Calibrated for latitude 41°.
(Inventory No. B 2.07))

Among the sundials described by Abu l-Ḥasan al-Marrākušī there are two portable ones, one of which is cylindrical and the other rectangular. Both are valid for a specific latitude between the Equator and ca. 66°30' North or South. The vertical shadow lines, ascertained beforehand, are transferred to the surface of the cylinder, which is made of wood or brass.[1]

A prerequisite for the construction and use of both sundials is a table showing the values of the vertical shadow lines for the duration of the hours of daytime and of the night at the beginning of the signs of the zodiac (for half hours, one third of an hour and other subdivisions). The surface of the cylindrical sundial, made of hardwood or brass, is divided from the top into twelve equal columns. Corresponding to these, the names of the signs of the zodiac are inscribed or engraved, beginning with Capricorn. A movable gnomon is affixed to a ring or by some other means to the cylinder, directly following the line of the zodiac. The values found by reading off the course of the shadow indicate the time in temporal hours and thus [**89**] the times of prayers. Al- Marrākušī displays his table for the latitude of 30° and his sketches for the

[1] Abu l-Ḥasan al-Marrākušī, *Ǧāmiʿ al-mabādiʾ wa-l-ġāyāt*, facsimile Frankfurt 1984, vol. 1, pp. 231-236; J.-J. and L. A. Sédillot, *Traité des instruments astronomiques des arabes*, Paris 1834-35 (reprint Frankfurt 1998, Islamic Mathematics and Astronomy, vol. 41), vol. 1, pp. 435 ff.

cylindrical dial as follows (see fig. above). For our model we have followed two Ottoman specimens of this type of sundial from the 18th century. One of them is in the museum of the observatory of Kandilli in Istanbul, the other belongs to the estate of Marcel Destombes (presently in the museum of the Institut du Monde Arabe, Paris).

On the question of the possible continuation of this type of sundial, v. A. J. Turner et al (Eds.), *Time*, The Hague 1990, no. 200, pp. 105, 114. There is represented the picture of a European specimen of about 1600 from a private collection:

(anonymous, late 16th c., Florence; Ist. e. Mus. di Storia della Scienza, Florence, Inv. no. 2457).

v. M. Dizer, *Astronomi hazineleri*, Istanbul 1986, fig. 17. Christiane Naffah, *Un cadran cylindrique ottoman du XVIIIème siècle*, in: Astrolabica (Paris) 5/1989/37-51.

The Sundial called ‹Locust Leg›

A simplified version of the above-mentioned sundial is described by al- Marrākušī (op. cit., p. 236; transl. Sédillot, op. cit., p. 440) by the name of *sāq al-ǧarāda* ("locust leg"). The instrument was known by this name probably because of its simplicity and because the user could carry it comfortably. In the Arabic-Islamic world the modesty of a gift is expressed by this term (*pāy-i malaḫ* in Persian, *çekirge budu* in Turkish).
Al- Marrākušī's sketch and the accompanying table are reproduced below:

Our model:
Measurements: 19 × 10 cm.
Brass, engraved.
(Inventory No. B 2. 06)

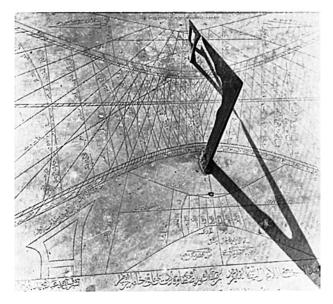
In our model we have followed the specimen which is preserved in the Cabinet des médailles of the Bibliothèque nationale in Paris. It was acquired in 1895 by M. Durighello in Beirut. The instrument had been constructed in 554/1159 by a certain Abu l-Farağ ʿĪsā, pupil of al-Qāsim b. Hibatallāh al-Aṣṭurlābī, for the Syrian ruler Nūraddīn Maḥmūd b. Zanğī (ruled 541/1146-569/1174).

Paul Casanova, *La montre du sultan Noûr ad dîn (554 de l'Hégire = 1159-1160)*, in: Syria. Revue d'art oriental et d'archéologie (Paris) 4/1923/282-299 (reprint in: Islamic Mathematics and Astronomy, vol. 88, Frankfurt 1998, pp. 242-262).

The Sundial
from the Omeyyad Mosque in Damascus

Model on the scale of ca. 1:2. Plate: 60 × 100 cm, inset in a table of hardwood. (Inventory No. B 2.01)

The sundial dating back to 773/1371 of the Umayyad mosque in Damascus, whose original form goes back to the time of the rule of Caliph al-Walīd b. ʿAbdalmalik (ruled 86/705-96/715), represents the climax of this type in the Arabic-Islamic world. It was made by the astronomer ʿAlī b. Ibrāhīm b. Muḥammad Ibn aš-Šāṭir[1] (b. 705/1306, d. 777/1375). The sources praise this scholar for the construction of his sundial, for his astronomical tables, his planetary theory, his universal instrument (*al-āla al-ǧāmiʿa*) and for his unique clock, which was constructed in such a way that it could run by itself, day and night, without the aid of sand or water, and could show the equal hours as well as the unequal hours.[2] In Damascus, Ibn aš-Šāṭir acted as mosque astronomer (*muwaqqit*) and as chief muezzin (*raʾīs al-muʾaḏḏinīn*).

The sundial which he made, measuring 1 × 2 metres, is of an unusual size. Until 1958, the original was thought lost. While repair work was being carried out, it was found again, broken into three pieces. Probably it had broken during a correction [**92**] undertaken in 1873 by the astronomer aṭ-Ṭanṭāwī.[3] He claimed to have found an error and

[1] An-Nuʿaimī, ʿAbdalqādir b. Muḥammad, *ad-Dāris fī taʾrīḫ al-madāris*, Damascus 1951, vol. 2, pp. 388-389; E. Wiedemann, *Ibn al Schâṭir, ein arabischer Astronom aus dem 14. Jahrhundert*, in: Sitzungsberichte der Physikalisch-medizinischen Sozietät zu Erlangen 60/1928/317-326 (reprint in: *Aufsätze zur arabischen Wissenschaftsgeschichte*, Hildesheim 1970, vol. 2, pp. 729-738); C. Brockelmann, *Geschichte der arabischen Litteratur*, vol. 2, pp. 126-127, 2nd supplementary volume, p. 157.

[2] This recalls the clock by Taqīyaddīn (infra, p. 119), which runs mechanically (driven, perhaps, by weights). Ibn aš-Šāṭir's clock is described by the historian Ḫalīl b. Aibak aṣ-Ṣafadī, who saw it in the astronomer's house, cf. E. Wiedemann, *Über die Uhren im Bereich der islamischen Kultur*, op. cit., p. 19 (reprint in: E. Wiedemann, *Gesammelte Schriften*, Frankfurt 1984, vol. 3, p. 1229).

[3] Abdul Kader Rihaoui, *Inscription inédite à la Mosquée des Omeyyades appartenant à un instrument astronomique*, in: Les annales archéologiques de Syrie (Damascus) 11-12/1961-62/209-212 (reprint in: E. S. Kennedy and Imad Ghanem (Eds.), *The Life and Work of Ibn al-Shāṭir, An Arab Astronomer of the Fourteenth Century*, Aleppo 1976, pp. 69-72).

then replaced the original with a copy, which is now in a passage at the foot of the minaret known as al-ʿArūs at the north side of the mosque. The sundial constructed by aṭ-Ṭanṭāwī is in fact a true copy of the original,[4] the three parts of which are now preserved in the Syrian National Museum in Damascus.

The sundial consists of three parts. The central part shows the unequal, or temporal, hours, with a precision of four minutes. The northern and the southern parts are calibrated for the equal, or equinoctial, hours.

Photograph of the original from *Centaurus*, vol. 16, to p. 288..

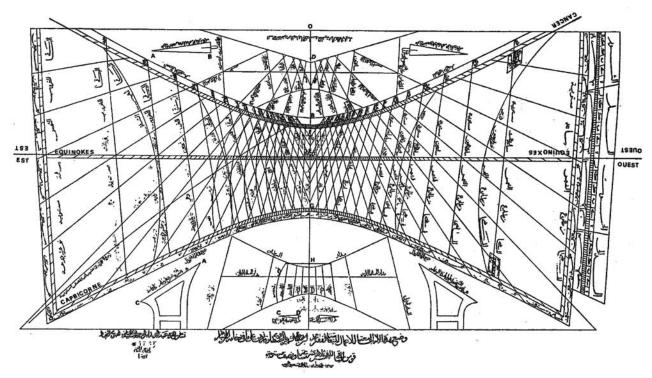
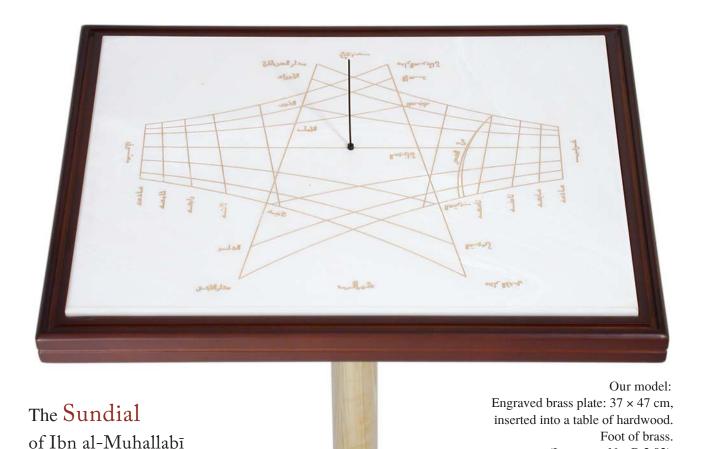
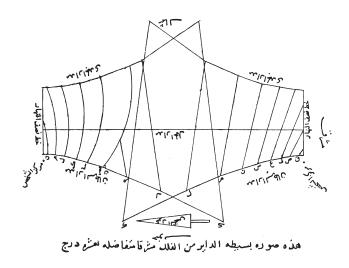



Figure from: *Centaurus*, vol. 16, p. 289.

[4] Louis Janin, *Le cadran solaire de la Mosquée Umayyade à Damas*, in: Centaurus (Copenhagen) 16/1972/285–298.

Our model:
Engraved brass plate: 37 × 47 cm,
inserted into a table of hardwood.
Foot of brass.
(Inventory No. B 2.02)

The Sundial of Ibn al-Muhallabī

The sundial, which Zainaddīn ʿAbdarraḥmān b. Muḥammad Ibn al-Muhallabī al-Mīqātī, an Egyptian mosque astronomer (*muwaqqit*), described and drew in 829/1426 in his book *ʿUmdat aḏ-ḏākir li-waḍʿ ḫuṭūṭ faḍl ad-dāʾir*, is preserved in a manuscript of the Chester Beatty Library in Dublin.[1] It was calibrated for the latitude of Cairo (30°). It shares its unusual, bipartite construction with the sundial of the Ibn Ṭūlūn mosque in Cairo of 696/1296, whose remains were depicted in the Napoleonic *Description de l'Egypte*[2] around 1800.

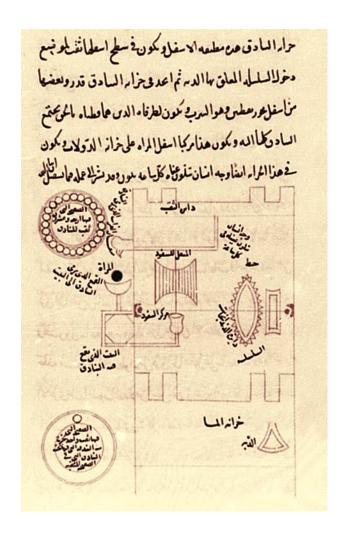
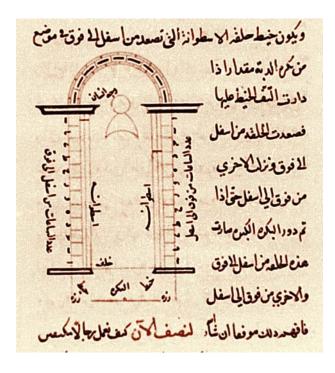
[1] No. 3641 (copied 858/1455), fol. 11b.
[2] L. Janin and D. A. King, *Le cadran solaire de la mosquée d'Ibn Ṭūlūn au Caire*, in: Journal for the History of Arabic Science (Aleppo) 2/1978/331–357 (reprint in: D. A. King, Islamic Astronomical Instruments, London 1987, no. XVI).

Pseudo-Archimedean

Water clock

in the Arabic Tradition

What is most probably a pseudo-Archimedean treatise on the water clock reached the Arabic-Islamic world quite early. The historian of science Ibn an-Nadīm[1] registered a *Kitāb Ālat sā'āt al-mā' allatī tarmī bi-l-banādiq* among the works by Archimedes known in the Islamic world. Donald R. Hill, who examined the booklet and translated it into English,[2] is of the opinion that the first four chapters were translated from a Greek copy and that the other parts originated in the Arabic-Islamic world. It was Baron Carra de Vaux[3] who drew attention to the existence in a Paris manuscript (Bibliothèque nationale, ar. 2468) of the treatise on the water clock ascribed to Archimedes. Subsequently Eilhard Wiedemann and Fritz Hauser translated the treatise into German using the Paris manuscript and two other manuscripts (London and Oxford).[4] Today a total of seven manuscripts are known. Our figures (see below) are taken from the Istanbul manuscript of the Ayasofya collection 2755 (fol. 70b-80b).

Our model:
Scale 1:1.5.
Height: 100 cm.
Plexiglass and brass.
(Inventory No. B 1.02)

[1] *Kitāb al-Fihrist*, ed. Gustav Flügel, Leipzig 1872, p. 266.
[2] D. R. Hill, *On the Construction of Water–Clocks. An Annotated Translation from Arabic Manuscripts of the Pseudo–Archimedes Treatise*, London 1976 (Occasional Paper. no. 4); idem, *Arabic Water–Clocks*, Aleppo 1981, pp. 15–35.
[3] *Notice sur deux manuscrits arabes*, in: Journal Asiatique (Paris), 8e sér., 17/1891/295 ff. (reprint in: Natural Sciences in Islam, vol. 37, pp. 17 ff.)
[4] *Uhr des Archimedes und zwei andere Vorrichtungen*. 1. *Über eine dem Archimedes zugeschriebene Uhr*, in: Nova Acta. Abhandlungen der Kaiserlich Leopoldinisch–Carolinischen Deutschen Akademie der Naturforscher in Halle 103/1918/163 ff. (reprint in: E. Wiedemann, *Gesammelte Schriften zur arabisch–islamischen Wissenschaftsgeschichte*, Frankfurt 1984, vol. 3, pp. 1629 ff., and in: Natural Sciences in Islam, vol. 37, pp. 57 ff.).

[**95**] The clock shows unequal temporal hours in two pillars, in each of which a weight passes an hour scale (on the left upwards, on the right downwards). Besides, after each hour a ball is released and, gliding through the beak of a bird, falls on to a bell. Moreover, the eyes in the face painted on the clock change their colour.
In the course of the day, or of the night, water, emptying uniformly from a tank, propels and guides the underlying mechanism, whose speed (over the water inlet) can be regulated according to the season by turning the end of the pipe, which is bent towards a semi-circular calendar sheet.

We are grateful to Professor André Wegener Sleeswyk, Rijksuniversiteit Groningen, for reconstructing the clock which he also described: *Archimedisch: de Mijlenteller en de Waterklok*. Natuurkundige Voordrachten N. R. 67, Lezing gehouden voor de Koninklijke Maatschappij voor Natuurkunde Diligentia te s'Gravenhage of 19 september 1988.

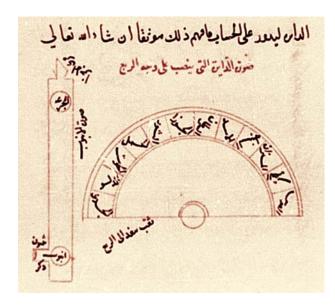



Fig. in the MS Istanbul, Ayasofya 2755 (fol. 70b-80b).

‹The Candle Clock with the Scribe›

In his book[1] al-Ǧazarī (ca. 600/1200) describes a candle clock (*finkān al-kātib*) made by one Yūsuf[2] al-Asṭurlābī, which he criticises from different aspects and replaces by his own construction. About its function he says: "The thing functions in the following way: the candle is inserted into the sheath at sunset, putting one ball after the other into the beak, up to 15 pieces. At that time the reed pen is outside the first degree. Now the candle is lit. Its flame is larger than that of a candle burning without this arrangement. This is a consequence of the wax collecting around the wick. The reed pen moves until its tip has reached the first mark; this is the first degree; then 1 degree of an hour (4 minutes) of the night has elapsed. When the tip reaches the 15th degree, the falcon throws a ball into the bowl under the candlestick. Thus it goes on until the night is over. There are as many balls in the bowl as there are hours in the night. The reed pen indicates the degrees, which do not result from the balls."[3]

Our model:
Total height: 60 cm.
Wood with engraved brass facings.
Brass candle holder.
Copper bowl with brass ornaments soldered to it.
Carved wooden figures.
(Inventory No. B 3.10)

Figure from al-Ǧazarī, *al-Ǧāmiʿ*.

[1] *Al-Ǧāmiʿ bain al-ʿilm wa-l-ʿamal* (MS Istanbul, Topkapı Sarayı, Ahmet III, No. 3472), 151-152; D. R. Hill, *The Book of Knowledge of Ingenious Mechanical Devices*, pp. 87-89.
[2] Some manuscripts have Yūnus instead of Yūsuf.
[3] Translated by E. Wiedemann and F. Hauser, *Über die Uhren im Bereich der islamischen Kultur*, op. cit., p. 157 (reprint, op. cit., p. 1367).

The Andalousian ‹Candle Clock with Twelve Doors›

Our model (opened):
Diameter: 50 cm.
Wood with engraved brass facings.
Beakers and mechanism of brass.
(Inventory No. B 3.09)

As the Andalusian polyhistorian Lisānaddīn Ibn al-Ḫaṭīb (Muḥammad b. ʿAbdallāh b. Saʿīd, d. 776/1374) reports, the ruler of Granada, Muḥammad V (ruled 1354-1359, 1362-1391) displayed a clock meant for night hours on the occasion of the Maulid (celebration of the birthday) of the Prophet Muḥammad in 763/1362. After the discovery of the manuscript of the third part of the *Nufāḍat al-ǧirāb fī ʿalāqat al-iġtirāb*—long thought lost—by Ibn al-Ḫaṭīb,[1] the Spanish Arabist E. García Gómez[2] edited the relevant text and translated it into Spanish.

The container of the clock consists of a covered twelve-sided wooden case with twelve doors. At the centre of the top cover stands a candle that is divided into twelve equal parts. As the candle burns down, twelve pegs weighted with a counterweight are released from the wax, one after the other. The pegs are affixed in such a way that the distance between them corresponds to one hour's burning of the candle. When one of the pegs falls down, in each case the counterweight pulls another peg with it, which releases a lattice in one of the doors. This falls down into a rail inside the clock, with the result that a rolled up scrap of paper with verses appears in the opening of the door, describing the hour of the night that has just elapsed. At the same time a ball falls into a beaker, producing an acoustic signal. The equal hours that have elapsed can be read off from the number of opened doors.

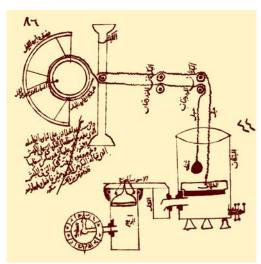
[1] Part 3, ed. by as-Saʿdīya Fāġiya, Rabat 1989, pp. 278-279.
[2] *Foco de antigua luz sobre la Alhambra desde un texto de Ibn al-Jaṭīb en 1362*, Madrid 1988, pp. 131 ff.; v. also J. Samsó, *Las ciencias de los antiguos en al-Andalus*, Madrid 1992, pp. 443-444.

Water Clock
of Riḍwān as-Sāʿātī

Our model:
Scale: 1:2.5.
Measurements:
130 × 80 × 180 cm.
Hardwood with inlaid
mother-of pearl
ornamentations.
Birds and bowls of brass.
On the back, glass doors
with brass frames.
Water container of copper
inside the clock.
(Inventory No. B 1.01)

The water clock constructed by Muḥammad b. ʿAlī (d. 618/1231), which was much damaged after his death, was repaired by his son, Riḍwān "the clock maker", who described it in detail with all its components in a book on clocks. According to our knowledge, two manuscripts of the book are preserved, one in Istanbul, Köprülü Collection 949, and the other in Gotha, Forschungsbibliothek 1348. The book was translated into German in 1915 by Eilhard Wiedemann after the Gotha manuscript.[1]

The water clock is constructed on the principle of unequal or temporal hours (*sāʿāt zamānīya*). The time from sunrise to sunset (or from sunset to sunrise) is divided into 12 parts each. The seasonal difference in the motion of the sun is [**99**] represented by adjusting the outflow nozzle for the water inside

[1] E. Wiedemann and Fritz Hauser, *Über die Uhren im Bereich der islamischen Kultur*, in: Nova Acta. Abhandlungen der Kaiserlich Leopoldinisch-Carolinischen Deutschen Akademie der Naturforscher in Halle 100/1915/176-266 (reprint in: E. Wiedemann, *Gesammelte Schriften*, Frankfurt 1984, vol. 3, pp. 1386-1476, and in Natural Sciences, vol. 41, pp. 196-286). The book was edited by M. A. Dahmān 1981 in Damascus on the basis of the Köprülü MS. Facsimile edition currently being prepared at the Institut für Geschichte der Arabisch-Islamischen Wissenschaften, Frankfurt. On the biography of the author, v. Ibn Abī Uṣaibiʿa, *ʿUyūn al-anbāʾ fī ṭabaqāt al-aṭibbāʾ*, Cairo 1299 H., vol. 2, pp. 183-184; Yāqʿū al-Ḥamawī, *Iršād al-arīb ilā maʿrifat al-adīb*, ed. D. S. Margoliouth, vol. 4, London 1927, pp. 211-212; aṣ-Ṣafadī, al-Wāfī bi-l-wafayāt, vol. 14, Wiesbaden 1982, pp. 128-129; C. Brockelmann, Geschichte der arabischen Litteratur, supplementary volume 1, Leiden 1937, p. 866.

the clock. The outflow nozzle is shifted to the position of the respective zodiac sign upon a plate, calculated for the calendar of Frankfurt on Main. The mechanism is driven by water, which flows out between sunrise and sunset (or vice versa) and, while doing so, propels a float. Uniform outflow is achieved through pressure compensation. The twelve segments of time of the temporal hours are indicated in such a way that, after each hour of the day, a door at the front opens. Moreover, a crescent of the moon above the doors indicates a quarter of these periods, by passing 48 golden nails one after the other from the left to the right. Aside from the optical indications, after each hour of the day two acoustic signals can be heard which occur when the figures of two falcons drop one ball each from their beaks into a beaker. During the night, twelve illuminated circles of a disc are released one after the other on the roof of the clock. These circles are illuminated by a lamp and indicate the hours.

Inside view of our replica.

Figure from the Köprülü MS.

The Water Clock
‹with the Elephant›

Our model:
Total height: 230 cm.
Elephant, figures
and tower of wood.
Domes and snakes of brass.
Water container of copper
inside the elephant.
(Inventory No. B 1.06)

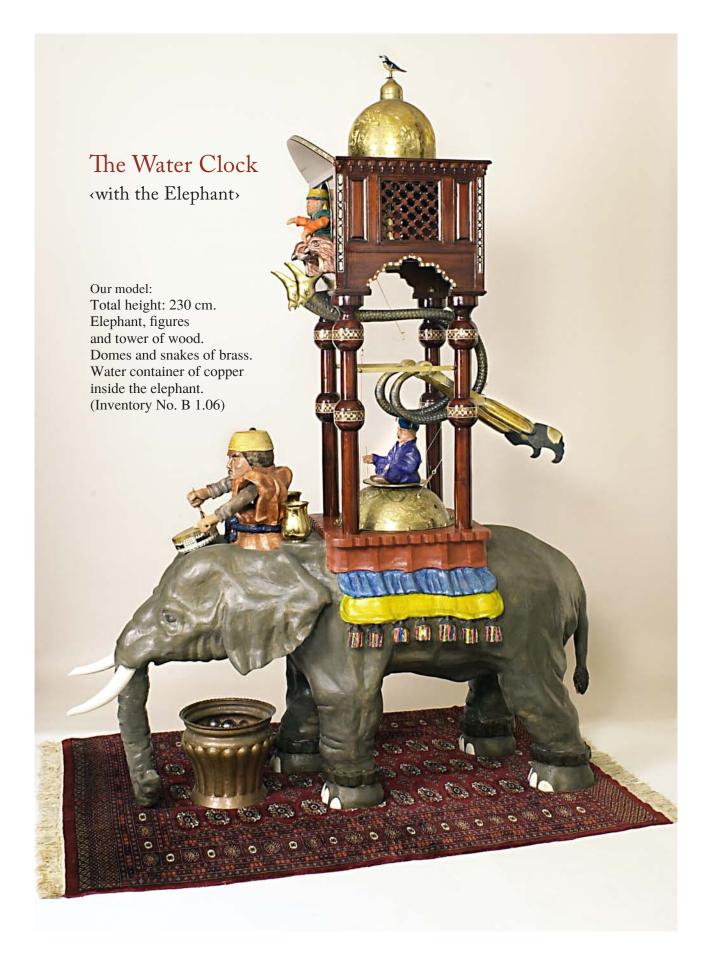
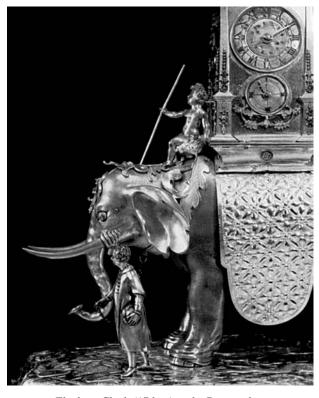



Fig. from al-Ǧazarī, *al-Ǧāmiʿ*, MS İstanbul, Topkapı Sarayı, Ahmet III, 3472, p. 90.

Reconstruction in original size of a water clock invented by al-Ǧazarī ca. 600/1200 and described in his book *al-Ǧāmiʿ bain al-ʿilm wa-l-ʿamal an-nāfiʿ fī ṣināʿat al-ḥiyal*.
This is a water clock which signals 48 intervals, spaced at 30 minutes each, thus indicating 24 equal hours. (For demonstration purposes the time interval was shortened to about three minutes). A "scribe", sitting on the back of the elephant, indicates these intervals by discreetly moving his reed pen after each half hour by one mark on the scale. The clock also shows half and full hours by a figure in the tower who lifts his right arm at each full hour and his left arm at each half hour. The mechanism is set in motion every 30 minutes by a hemispherical float [**102**], which drifts on a basin filled with water inside the elephant. The float has a precisely calculated hole in its base through which so much

water within 30 minutes enters that it no longer has buoyancy and sinks. When this happens, a ball in the tower is released via a thread and, with its downward movement, sets various figures in motion. A bird turns around, the figure in the tower lifts his arms one after the other, two snakes move downwards and pull the float again to its original position. The scribe moves and the figure sitting on the head of the elephant strikes the elephant with a whip in his right hand and a drum with a stick in his left hand.

Literature: al-Ǧazarī, *al-Ǧāmiʿ*, facsimile Frankfurt 2002, pp. 88-96; E. Wiedemann, *Über die Uhren im Bereich der islamischen Kultur*, op. cit., pp. 116-134 (reprint, op. cit., p. 1326-1344); D. R. Hill, *The Book of Knowledge of Ingenious Mechanical Devices*, pp. 58-70.

Elephant Clock (17th c.) in the Bayerisches Nationalmuseum.

The elephant clock seems to have stirred the imagination of makers of figurine clocks in Europe in the 16th and the 17th centuries. Several elephant clocks are known at present. One of them dates from the early 17th century and is in the Bayerisches Nationalmuseum in Munich.[1] A second one, from ca. 1580, belongs to a private owner, also in Munich.[2] On the third specimen, made ca. 1600 in Augsburg and in a private collection in 1980, see Die Welt als Uhr, p. 266, no. 92.

Elephant Clock (ca. 1600) in a private collection.

[1] *Die Welt als Uhr*. Deutsche Uhren und Automaten 1550-1650, ed. Klaus Maurice and Otto Mayr, Munich 1980, p. 266, no. 93.
[2] *Die Welt als Uhr*, p. 264, no. 91.

A Beaker Clock of al-Ǧazarī

Our model:
Brass, embossed, partly engraved.
Wood and plexiglass.
Carved figure of pear-tree wood.
Electric pump for refilling the water.
(Inventory No. B 1.10)

Among the numerous clocks listed by al-Ǧazarī (ca. 600/1200) in his *Ǧāmiʿ bain al-ʿilm wa-l-ʿamal*, he describes the beaker clock as his own invention:[1] "The ruler, aṣ-Ṣāliḥ Abu l-Fatḥ Maḥmūd b. Muḥammad b. Qarā-arslān … requested me to make an instrument which has no chains, balances (*mīzān*)[2] or balls, which does not change quickly and does not decay, and from which one can see the passage of the hours and their divisions. It should have a beautiful shape and be a companion during journeys and at home. I exerted my mind and made it in the following way. The clock consists of a beaker on a base, on the top it is covered with a flat lid. Around its periphery runs a chiselled gallery (*šurfa*) and on the gallery is a delicate horizontal ring, divided into 217½ (=14 ½ × 15) divisions; each 15 divisions represent one equal hour."

[1] Facs. ed. Ankara, pp. 119-126; German transl. E. Wiedemann and F. Hauser, *Über die Uhren im Bereich der islamischen Kultur*, in: Nova acta. Abhandlungen der Kaiserlich Leopold inisch-Carolinischen Deutschen Akademie der Naturforscher (Halle) 100/1915/1-272, esp. p. 134-141 (reprint in: *Gesammelte Schriften*, vol. 3, pp. 1211-1482, esp. pp. 1344-1351); Engl. transl. D. R. Hill, *The Book of Knowledge of Ingenious Mechanical Devices*, op. cit., pp. 71-74.

[2] On this Wiedemann remarks: "Balances and apparatuses for tilting were used in numerous ingenious devices."

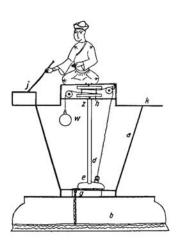



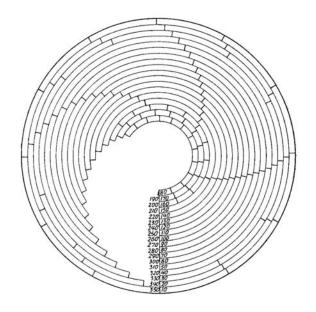
Fig. from E. Wiedemann, *Gesammelte Schriften*, vol. 3, p. 1345.

"A scribe is seated on a seat at the centre, holding in his hand a reed pen, the tip of which is on the ring a little outside the first mark on the scale. It moves nearly imperceptibly from the beginning of the day to the left uniformly until it reaches up to the first division of the 15 divisions of the equal hours and one hour of the day has elapsed."[3]

Inside the container there is a water clock. It shows hours of the day, to be read from the position of the reed pen on the cover above. For this, the time between sunrise and sunset is divided into twelve divisions, the so-called temporal hours. The seasonal difference in the motion of the sun is taken into account before the start by adjusting the reed pen towards the diameter, where various scales are marked (see above).

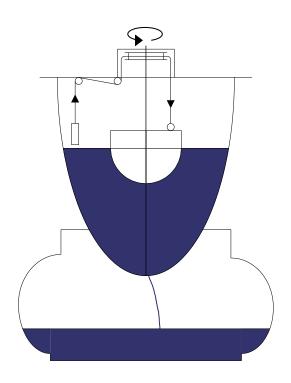
In order to ensure a constant angular velocity of the indicator, the problem of water pressure, which depends on the volume, has to be solved in all kinds of water clocks; there were various approaches chosen for this (see above).

The decisive achievement in the present case consists in the construction of a beaker shape which balances the decreasing water pressure with the sinking water level through a reduced volume of flowing water (i.e. the container becomes narrow in such a way that the water level sinks uniformly, despite the decreasing outflow; in the manuscripts (see above) the beaker is seen to be drawn in the shape of a funnel; however, the text describes[4] how the parabola—which we took as the basis for our model—was achieved empirically). A float, sinking on a central spindle, constantly turns the scribe with his pen by means of a cord and a wheel.

Drawing from al-Ǧazarī, MS Istanbul, Ayasofya 3606.

The longest day in the region where the clock was designed consisted of 14.5 hours. The exact calculation of the diameter of the cord pulley results in the scribe turning around himself exactly once between sunrise and sunset on this day. The time can be read on this day at the outermost scale marked on the disc, provided the reed pen was put on this position. The shortest day has 9.5 hours. These can be read off the inner circular ring of the disc.

[3] Translation (with minor changes) from E. Wiedemann, *Über die Uhren im Bereich der islamischen Kultur*, op. cit., pp. 134-135 (reprint, op. cit., pp. 1344-1345).

[4] ibid, p. 136 (reprint p. 1346).

The division of the disc was described as follows by E. Wiedemann after al-Ǧazarī:

“This figure gives, according to the statements of the text, an overview of the disc of the beaker clock for the ‘temporal’ hours. The division into hours was drawn completely in only some of the circles”
(Wiedemann, *Gesammelte Schriften*, vol. 3, p. 1350).

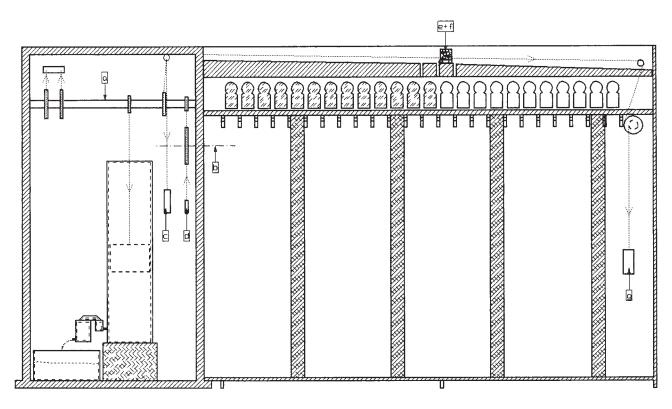
“The division of the disc was probably as is represented in the figure above for a dial equipped with 18 divisions (corresponding to 10 days each). All the 18 arcs of the circle started at an incised radius which represented the starting position of the scribe when the beaker was full. From here they progressed towards the left until each of them reached a radius that represented the position of the reed pen or, rather, of the dial at the sunset of the day corresponding to the relevant arc; provided the clock had been set in motion at sunrise. Since the outermost arc represented the longest day, the result was a system of concentric arcs of the circle which became shorter and shorter towards the middle. Since, according to the description, the outer wall of the beaker had been hammered in such a way that the hourly rotation was almost constant, and since the outermost arc representing the longest day of 14 1/2 hours subtended an angle at the centre of 360°, the innermost arc representing the shortest day of 9 1/2 hours subtended an angle of only 236°. Thus, of the 18 arcs each subsequent arc was approximately 7.3° shorter than the preceding one. The individual arcs were then divided into 12 equal divisions, each one separately; in addition, the outermost one was also divided into 14 1/2 divisions (this latter division was omitted in the figure above, with the former being executed completely in the case of a few arcs, while the remaining ones were only divided into four divisions). Each arc represented—assuming a year of 360 days—10 days each, both with decreasing and increasing daylight. Therefore, at each arc two numbers had to be entered for the days corresponding to it. In any case, these numbers were engraved on both sides of the inscribed radius, as shown above. If the numbering was begun at the longest day, then with the shortest day only one number—namely 180—had to be entered; but if, on the other hand, the user began with the numbers at the shortest day, then the same was the case with the longest day. With such a method of entering the numbers, these came to be always written on the same side of the proper arc of the circle. An arc which was at a distance of 180 from that of the day always represented the arc of the night.”[5]

Cross-section of our model with
a beaker in the shape of a parabola.

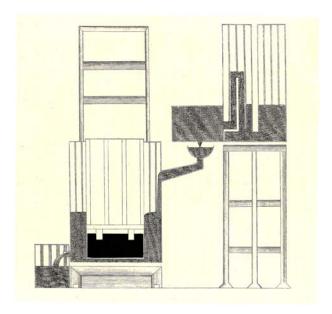
[5] Translated (with minor changes) from E. Wiedemann’s version, ibid., pp. 139-140 (reprint pp. 1349-1350).

Water Clock
from Fez

Replica of a clock whose original is in the Qarawīyīn Mosque in Fez (Morocco) and was repaired by the Institute for the History of Arabic-Islamic Sciences. The maker of the original was called Abū Zaid ʿAbdarraḥmān b. Sulaimān al-Laǧǧāʾī. He constructed the clock in 763/1362 at the request of Sultan Ibrāhīm b. Abi l-Ḥasan b. Abī Saʿīd.

Our replica:
Wood, lacquered.
The wooden elements, elaborately painted over in a modern style, were made in Morocco.
Brass clock face, diameter 46 cm. 24 bronze bells.
All water containers inside the clock, made of copper.
Width: 4.30 m; height: 2.40 m.
(Inventory No. B 1.04)

Construction scheme of the water clock from Fez.

This is the oldest extant water clock which divides the day into 24 equal hours. These can be read off a dial, which is divided into 4 minutes each. Every four minutes a small ball and every hour a large ball fall into one of the 24 brass bowls, producing a sound. Altogether 360 small balls and 24 large ones fall within 24 hours into the bowls and from there go into a collective receptacle. In addition to the acoustic signals, at the beginning of each hour one of the wooden doors closes, which give an overview of the hours elapsed and can even be recognised from afar. The mechanism is set in motion by water flowing out; this results in the sinking of a float to which all the functional components are attached by rolls of cord. The uniform outflow is achieved by means of a precisely calculated container for pressure compensation. An ingeniously designed, surprisingly advanced technology ensures that the two carriages move opposite to the direction of the sinking of the float.

Literature: ʿAbdalhādī at-Tāzī, *Ǧāmiʿ al-Qarawīyīn: al-masǧid wa-l-ǧāmiʿa bi-madīnat Fās*, Beirut 1972, vol. 2, pp. 325-326;

Derek J. DeSolla Price, *Mechanical Water Clocks of the 14th Century in Fes, Morocco*, offprint from: Proceedings of the 10th International Congress of the History of Sciences, Ithaca, 26 VIII – 2 IX 1962, Paris: Hermann 1964 (8 pp.), pp. 3-5.

SPANISH–ARABIC CLOCKS

In the eastern and central areas of the Islamic world technologies were cultivated which quickly reached the western part of this region too, and were disseminated and improved there; without doubt clock-making was also among those technologies. At present we are nowhere near being able to describe exactly the stages of development which clock-making underwent in continuation of the achievements of the preceding periods in the eastern and western areas of Islam. In this connection it is of great importance that in a book which basically represents a compilation of Arab-Islamic sciences, the *Libros del saber de astronomía* commissioned by Alfonso X of Castile and written in Toledo around 1267-68, five clocks are described in a special chapter: a water clock, a mercury clock, a candle clock and two sundials.

From: *Libros del saber de astronomía*,
Madrid 1866, vol. 4, p. 71.

Our model:
Measurements: 70 × 36 × 180 cm.
Plexiglass and brass.
Cabinet of walnut and plexiglass.
(Inventory No. B 1.03)

1.

Spanish–Arabic Water Clock[1]

The *relogio dell agua* is one of the five clocks mentioned in the *Libros del saber de astronomía*. Its detailed discussion is accompanied by a sketch. The compiler of the book is of the opinion that the description of this clock in his sources was "very meagre". According to these, the water container had simply been bored through at the bottom, with the result that the water does not flow out uniformly, but less and less because of the decreasing pressure accompanying the diminishing volume. He had rectified this defect by his own "subtle inventions". In reality, the provision for a uniform outflow of water, not only for water clocks, but also for other hydraulic automata, was known and commonly used in the Arabic-Islamic world, as had been done earlier by the Greeks. What is measured is the unequal temporal hours.

As the model shows, in this clock the water from the container, which is placed at a higher level, flows across a pressure compensator, providing buoyancy to a float in the lower container. By this means a table affixed to it is pushed above the top edge of the container, where the time for the zodiacal sign concerned can be read off.

Our model was constructed by Eduard Farré (Barcelona).

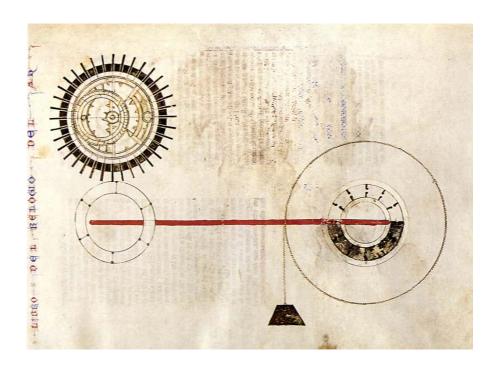
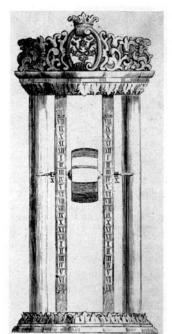
[1] Donald R. Hill, *Arabic Water-Clocks*, op. cit., pp. 126–130; Alfred Wegener, *Die astronomischen Werke Alfons X.*, in: Bibliotheca Mathematica (Leipzig), 3rd series 6/1905/129–185, esp. p. 162–163 (reprint in: Islamic Mathematics and Astronomy, vol. 98, Francfort 1998, p. 57–113, esp. pp. 90–91).

2. Mercury Clock

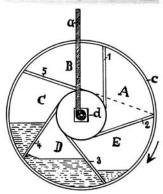
The fourth clock mentioned in the special chapter of Libros del saber de astronomía is a mercury clock (relogio dell argent uiuo). A. Wegener[1] describes it as follows: “The mechanism of this clock consists of a wheel which completes only one rotation in 24 hours. The propelling force is a weight; the escapement is provided by mercury inside the wheel and gives way to the pull of the weight only gradually, slowed down by transverse walls with only very small openings. The rotation of this wheel is transferred to an astrolabe which, in a way, can be considered the very ingenious dial of this clock, on which can also read off, besides the hours, the position of the sun and the stars at the same time and, in general, the entire view of the sky for that moment. It is said that it was also possible to combine the clockwork with a celestial globe instead of an astrolabe. Through a suitable attachment of bells it could be turned into a kind of alarm clock.”

On the process of the survival and the impact of this clock on subsequent developments in Europe, there is an excellent essay entitled *The Compartmented Cylindrical Clepsydra*[2] by Silvio A. Bedini. He establishes that the *Libros del saber de astronomía* were translated in Florence into Italian[3] before 1341 and draws the conclusion: “The existence of this Italian codex is of considerable significance with relation to the subsequent development of the mercury clock in Europe and particularly in Italy, despite the fact that horological writers of the next six centuries made no reference to it.”[4]

More than three hundred years after the Alfonsine compilation, the mercury clock appears again in European literature, viz. in a book by Attila Parisio that appeared in 1598 in Venice, in which Parisio claims to be the inventor of the clock [**111**] (*Discorso Sopra la Sua Nuova Inventione d’Horologio con una sola Ruota*).[5] In the clock which he allegedly invented the mercury was replaced by water. Shortly after the publication of Parisio’s book, the description and illustration of this clock appeared

Our model:
Wooden case.
Measurements:
22 × 30 × 55 cm.
Clock face of brass, engraved.
Wooden wheel with compartments
of plexiglass. Diameter: 25 cm.
Constructed by Eduard Farré (Barcelona)
(Inventory No. B 3.04)

[1] *Die astronomischen Werke Alfons X.*, in: Bibliotheca Mathematica (Leipzig), 3rd series 6/1905/129-185, esp. p. 163 (reprint in: Islamic Mathematics and Astronomy, vol. 98, Frankfurt 1998, pp. 57-113, esp. p. 91); v. also E. Wiedemann and Fritz Hauser, *Über die Uhren im Bereich der islamischen Kultur*, op. cit., pp. 18-19 (reprint in: *Gesammelte Schriften …*, vol. 3, pp. 1228-1229).

[2] Published in: Technology and Culture (Chicago) 3/1962/ 115-141.

[3] While establishing this, Bedini profited from a short monograph about the topic by Enrico Narducci, *Intorno ad una traduzione italiana fatta nell’anno1341 di una compilazione astronomica di Alfonso X. re di Castiglia*, Rome 1865 (reprint in: Islamic Mathematics and Astronomy, vol. 98, Frankfurt 1998, pp. 5-36).

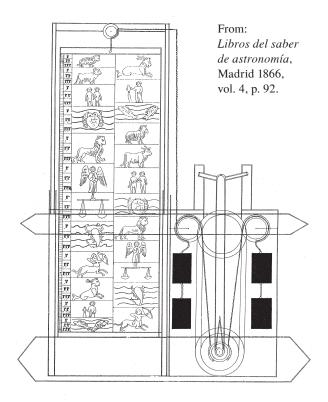
[4] Bedini, op. cit., p. 118.

[5] ibid, p. 118.

as one of the "fundamentals of motive forces" (*raisons des forces mouvantes*) by Salomon de Caus (1615).[6]

The clock is also mentioned by Johannes Kepler.[7] In this form, which was basically nothing more than the specimen described in the *Libros del saber de astronomía*, whose 12-part barrel was merely half filled with water instead of mercury and which is designated by Bedini as "compartmented cylindrical clepsydra", this clock enjoyed wide dissemination in Europe in the 17th and 18th centuries. One of several types, differing slightly, is connected with the name of Pater Francesco Eschinardi (1648).[8] A similar apparatus was presented by the three Campani brothers (1656) to Pope Alexander VII.[9] The barrel of this clock again contained mercury instead of water and it functioned about as inaccurately as the others. Still, it was praised by the Pope as an important invention.[10] Nothing remains of the Campani clock except the description of a few of the features of its construction.[11]

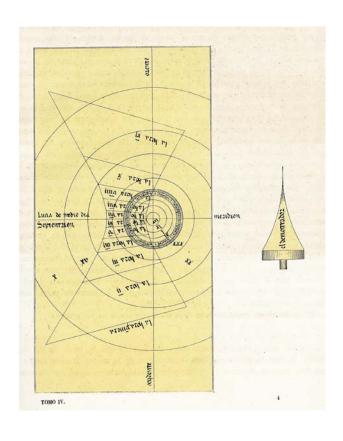
After the clock by the Campani brothers, other versions appeared, now filled again with water instead of mercury. Mention may be made of the makers: Domenico Martinelli (1669),[12] Dom Jacques Allexandre, who claimed in 1734 that this type of clock was an invention of Charles Vailly,[13] and M. Salmon who, in an illustration in his *L'Art Du Potier D'Etain*, depicts the production of several cylindrical water clocks and thus establishes that they were very popular in France, particularly in the 18th century.[14]

Fig. (above): From *Libros del saber de astronomía;* (on the right): Salomon de Caus, *Les Raisons des Forces Mouvantes*, after Bedini, op. cit., fig. 6.

[6] *Les Raisons des Forces Mouvantes, avec diverses Machines, tant utiles que plaisantes, aus quelles sont adioints plusieurs desseings de grotes et fontaines*, Frankfurt: J. Norton, 1615, 1644 (v. Bedini, op. cit., p. 124).
[7] v. Anton Lübke, *Die Uhr. Von der Sonnenuhr zur Atomuhr*, Düsseldorf 1958, p. 78; Bedini, op. cit., p. 125.
[8] Bedini, op. cit., p. 125.
[9] ibid, pp. 127–128.
[10] ibid, p. 129.
[11] ibid, p. 129.
[12] ibid, pp. 131–135.
[13] ibid, p. 136.
[14] ibid, pp. 137–138.

From:
Libros del saber de astronomía, Madrid 1866, vol. 4, p. 92.

3.
Spanish-Arabic Candle Clock

This clock is the third to be listed, under the name relogio de la candela, in the chapter on clocks of the Libros del saber de astronomía. There it is described at length and illustrated with diagrams.[1] On the side where it is burning, the candle sits in a sleeve, so that as it gets shorter its base can be pushed up by a counterweight. A thread connected to the bottom and loaded with an additional further counterweight then pulls the tablet up on which a table of the unequal hours (temporal hours) on the corresponding calendar days is inscribed. On the horizon of the clock the time can be read off when the date is known. The table is valid for only one specific climate zone.

Our model:
Brass.
Total height: 42 cm.
(Inventory No. B 3.08)

The model was constructed by Eduard Farré (Barcelona).

[1] A. Wegener, *Die astronomischen Werke Alfons X.*,pp. 163–164 (reprint., pp. 91–92).

4. Spanish-Arabic Sundial

Our model:
Engraved brass plate (30 × 60 cm),
inserted in a table of hardwood.
Foot of brass.
(Inventory No. B 2.04)

The relogio de la piedra de la sombra is listed as the fourth among the clocks of the *Libros del saber de astronomía* and is illustrated with a figure. The spiritual father of this compilation, Alfonso X, opines that he had “for the construction of the sun-dial found no book which was complete in itself, so that one did not need any other book for the work.” It was for this reason, he said, that he had commissioned a detailed description.[1]

Fig. from the modern edition of the *Libros del saber de astronomía*, Madrid 1866, vol. 4, p. 17. This reconstruction served as the prototype for our model.

[1] v. A. Wegener, *Die astronomischen Werke Alfons X.*, op. cit., p. 162 (reprint., p. 90).

Sundial

of Ibn ar-Raqqām

Our model:
Diameter: 25 cm.
Brass, etched.
(Inventory No. B 2.13)

In the 44th chapter of his "Treatise on the Knowledge of Shadows" (*Risāla fī ʿIlm aẓ-ẓilāl*), Abū ʿAbdallāh Muḥammad b. Ibrāhīm ar-Raqqām[1] (d. 715/1315) describes a sundial which is connected to a floating compass.[2] This astronomer, mathematician and physician from Murcia was one of the scholars who were active under the Nasrids in Granada.

The lodestone, fixed to a piece of wood, serves to regulate the north-south direction for the sundial engraved on the lid of the wooden bowl. The dial is kept in equilibrium by being suspended from silk threads. A very similar apparatus (v. the next model) is ascribed to Pedro Nunes (1537).

[1] Ibn al-Ḫaṭīb, *al-Iḥāṭa fī aḫbār Ġarnāṭa*, vol. 3, Cairo 1975, pp. 69–70; C. Brockelmann, *Geschichte der arabischen Litteratur*, 2nd supplementary volume, Leiden 1938, p. 378. The only known manuscript of the treatise is in the library of the Escorial 918/11 (fol. 68b–82a). It was studied and published by Joan Carandell, *Risāla fī ʿilm al-ẓilāl de Muḥammad Ibn al-Raqqām al-Andalusī*, Barcelona 1988.
[2] v. *Risāla fī ʿilm al-ẓilāl*, ed. Carandell, pp. 208–209, 313.

Our model:
Diameter: 26 cm.
Brass, etched.
(Inventory No. B 2.15)

Sundial
of Pedro Nunes (1537)

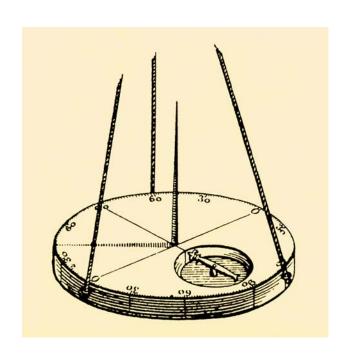
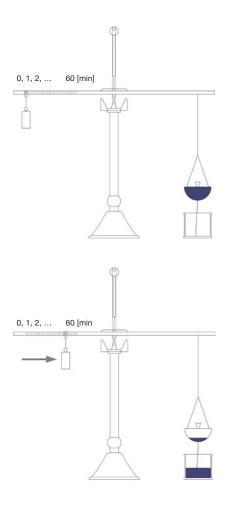



Figure from:
Instrumentos de navegación: Del Mediterranéo al Pacifico,
Barcelone n.d., p. 84.

Water Clock

with Alarm Function

Our model:
Measurements: 60 × 60 × 30 cm.
Wheel and frame of hardwood.
Water containers of clay.
Brass dial with engraved Roman numerals (I-XXIV).
Bells of bronze.
(Inventory No. B 1.05)

The clock is described in the Latin manuscript 225 of the Benedictine monastery Santa Maria de Ripoll (at the foot of the Pyrenees). The manuscript, which might date back to the 13th century, is now in the Archivo de la Corona de Aragón in Barcelona. The mechanism of the clock betrays similarity to the first water clock described in al-Ǧazarī's book.[1] The relatively simple mechanism is driven by a float in the lower container, which moves up as the water flows in and sets the wheel in motion. A small tin plate, placed on the rim of the wheel upon any given notch (= time of the day or night), drops a lead weight at the desired time while rotating. This results in the unbolting of a clapper which, connected to a spool, is put into a rotary motion and, for about 5 seconds, strikes against the bells. Since the water flows with varying speed, due to lack of pressure compensation, a uniform measurement of time is not possible.

The model was built by Eduard Farré (Barcelona), who also described the construction:
A Medieval Catalan Clepsydra and Carillon,
in: Antiquarian Horology (Ticehurst, East Sussex) 18/1989/371-380.

[1] Francis Maddison, Bryan Scott, Alan Kent, *An Early Medieval Water-Clock*, in: Antiquarian Horology (Ticehurst, East Sussex), 3/1962/348–353; Donald R. Hill, *Arabic Water-Clocks*, Alep, 1981, pp. 125–126; *El Legado Científico Andalusí*, Madrid, 1992, p. 198.

Balance of Minutes

al-mīzān al-laṭīf al-ǧuzʾī

0, 1, 2, ... 60 [min]

0, 1, 2, ... 60 [min

Our model:
Brass, partly etched.
Height: 120 cm.
Beam of the balance suspended
with little friction, width: 120 cm.
(Inventory No. B 1.11)

The physicist ʿAbdarraḥmān al-Ḫāzinī describes[1] in the eighth chapter of his *Mīzān al-ḥikma* (515/1121) a 'time balance' which serves for measuring the 24-hourly rotation of the heavens. This balance, called *mīzān as-sāʿāt wa-azmānihā*, consisted of a reservoir of water or sand, suspended from the beam of the balance and endowed with a precisely calculated small opening. By balancing the loss of weight through shifting of weight on the arm of the balance, the time elapsed could be read from a corresponding scale, almost as if one was weighing the weight of the minutes.

The 'absolute balance' (*al-mīzān al-kullī*) was contrived to run for 24 hours and was correspondingly large; it had two sliding weights and scales for hours and minutes. Our model is a reconstruction of the smaller 'balance of minutes' (*al-mīzān al-laṭīf al-ǧuzʾī*), which runs for one hour only and is equipped with a scale of 60 minutes for this purpose (*at-taqsīm as-sittīnī*).

[1] al-Ḫāzinī, *Mīzān al-ḥikma*, Ed. Hyderabad, 1359/1940, pp. 164–165.

Mechanical Clocks
of Taqīyaddīn

The Ottoman scholar of Arabic origin, Taqīyaddīn Muḥammad b. Maʿrūf (b. 927/1521 in Damascus, d. 993/1585 in Istanbul), wrote in 966/1559, when he was qāḍī at Nābulus, his book on mechanical clocks, *Kitāb al-Kawākib ad-durrīya fī waḍʿ al-bingāmāt ad-daurīya*.[1] This work was preceded, among others, by his book on pneumatic apparatuses, *aṭ-Ṭuruq as-sanīya fi l-ālāt ar-rūḥānīya*,[2] written in 959/1552, in which he devotes some space to the construction of water clocks.

In his book of clocks Taqīyaddīn laments that in the Arabic-Islamic world it was mainly water clocks and sand clocks which were discussed, the mechanical clock being neglected. Besides water and sand, he was concerned about the other motive power, with the aim, as he puts it "of pulling a weight with minor force for a long time across a long distance" (*ǧaḏb aṯ-ṯaqīl bi-qūwa qalīla … zamānan ṭawīlan fī masāfa baʿīda*).[3] However, here it should be noted that he refutes the idea of a perpetuum mobile (see below, vol. V, p. 61).[4]

Taqīyaddīn, who also displays in his other works great competence in working with cogwheel systems, seems to have been inspired—at least in the use of the crown escapement and the use of the ascending spiral line on the outer casing of a truncated cone—by European mechanical clocks which had found their way into the Ottoman empire during his lifetime. In any case, he makes no secret of it that he knew of such European clocks. On the other hand, a possible influence from the Arabic-Islamic world upon Europe in the development of the mechanical clock is still an open question. It is known that in Islamic countries escapements were used with water and mercury clocks. The question remains, "when the simple escapement came into use in clocks with cogwheels."[5]

In his book Taqīyaddīn describes about ten clocks, which he divides into two groups: clocks driven by weights and clocks with a spiral spring. The first kind he calls *bingāmāt siryāqīya*, the latter *bingāmāt daurīya*.

Because of the idea of introducing time as an element of observations, Taqīyaddīn decided to construct a large astronomical clock (*bingām raṣadī*). He described it at length in his treatise *Sidrat al-muntahā*[6], which is devoted to the instruments of the Istanbul observatory. We recognise in it a most interesting planetary model clock. A figure of its dial for hours, degrees and minutes is preserved in the autograph[7] of the treatise:

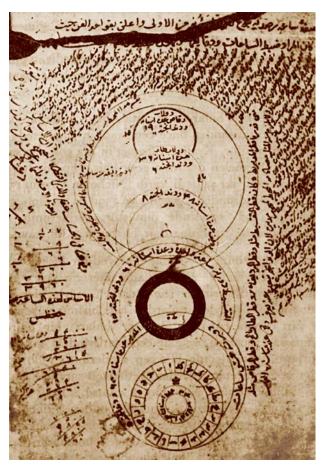
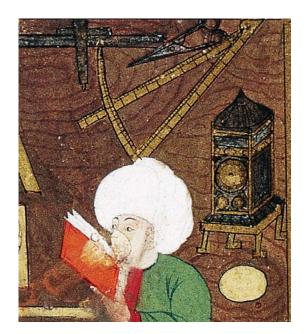



Fig. from Tekeli, *16'ıncı asırda Osmanlılarda saat*, p. 13.

[1] Preserved in four manuscripts, v. *Osmanlı astronomi literatürü tarihi*, vol. 1, Istanbul, 1997, p. 206; ed. and translated into English and Turkish by Sevim Tekeli, *16'ıncı asırda Osmanlılarda saat ve Takiyüddin'in «Mekanik saat konstrüksüyonuna dair en parlak yıldızlar» adlı eseri*, Ankara 1966.

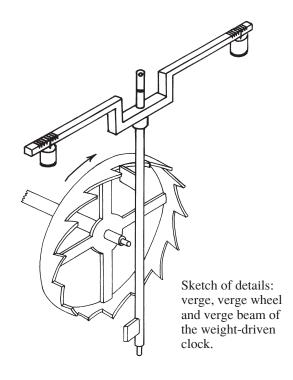
[2] Ed. by Aḥmad Y. al-Ḥasan, in *Taqīyaddīn wa-l-handasa al-mīkānīkīya al-ʿarabīya*, Aleppo 1987.

[3] Sevim Tekeli, *16'ıncı asırda Osmanlılarda saat,* p. 220.

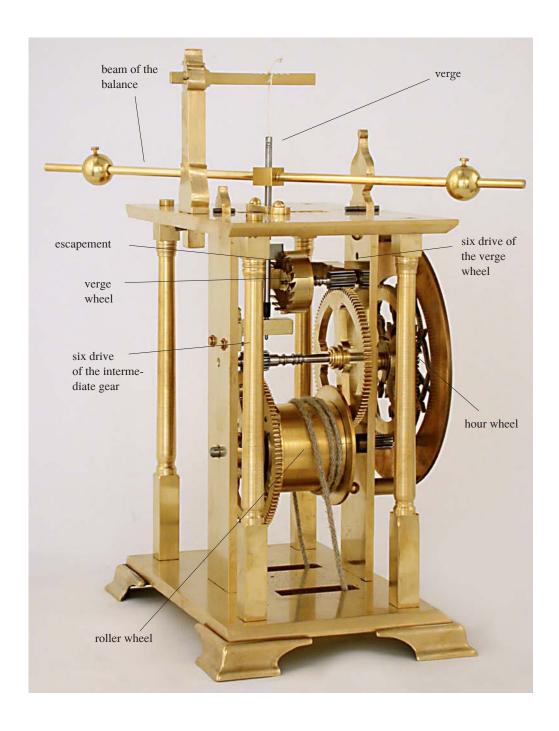
[4] ibid., p. 218.

[5] Feldhaus, *Die Technik*, op. cit., col. 1216.

[6] v. Sevim Tekeli, *Takiyüddin'in Sidret ül-Müntehâ'sında aletler bahsi*, in: Belleten (Ankara) 25/1961/213–238, esp. pp. 226–227, 237–238; idem, *16'ıncı asırda Osmanlılarda saat,* pp. 11–12.

[7] İstanbul, Kandilli Rasathanesi, MS No. 56; S. Tekeli, *16'ıncı asırda Osmanlılarda saat,* op. cit., p. 13.

Detail from a miniature of Taqīyaddīn's team.

Our model:
Brass, copper, strass stones.
Height: 25 cm.
(Inventory No. B 3.12)

Taqīyaddīn's 1st Weight Driven Clock (1559)

The simplest among the weight driven clocks (*bingāmāt siryāqīya*) described by Taqīyaddīn in his book on clocks of 966/1559 contains a clockwork whose speed is regulated by a crown escapement. The external appearance of the clock and its measurements are not mentioned in the text. We can gather some idea of it from the drawing of a table clock to be seen in the picture of Taqīyaddīn and his team at work in the observatory in Istanbul (see above, vol. II, pp. 34 ff., 53 ff.).
"The clock has a roller wheel with 54 teeth, which interlocks with the six drive of the intermediate gear. The latter has 48 teeth and interlocks with the six drive of the verge wheel with 21 teeth. The verge carries a balance beam with weights," according to G. Oestmann and F. Lühring (Bremen), who constructed the clock for us.

Sketch of details: verge, verge wheel and verge beam of the weight-driven clock.

beam of the balance

verge

escapement

six drive of the verge wheel

verge wheel

six drive of the intermediate gear

hour wheel

roller wheel

Taqīyaddīn's 2nd Clock
with Spring Tension and Striking Mechanism (1559)

On the right: (a), constructed by Eduard Farré (Barcelona), next page (b) constructed by G. Oestmann and F. Lühring (Bremen).

Our models:
a) Brass, steel, wood.
Spring mechanism with key.
Height 40 cm.
(Inventory No. B 3.13)

In the second part of his book Taqīyaddīn describes a clock with spring tension, striking mechanism and indicators for the phases of the moon, the days of the week, hours and degrees. For the museum of the Institute two models of this clock were made which, compared with one another, have advantages and disadvantages. The advantage of model a) consists in its having a complete dial that shows all the four of the indicators envisaged by Taqīyaddīn, while with b) the indicators for the days of the week and the degrees are missing. The disadvantage of a) is that it makes do with a simple tension spring instead of using the spiral spring described and shown clearly by Taqīyaddīn. Taqīyaddīn requires not only this spiral spring, but a second one for the striking mechanism. If one leaves aside the difference between the driving gears, the clockwork is identical with that of the clock driven by weights.

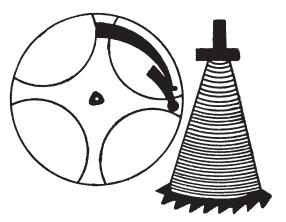
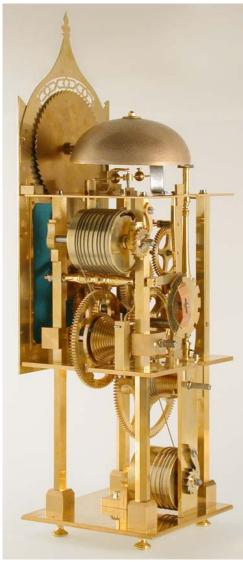
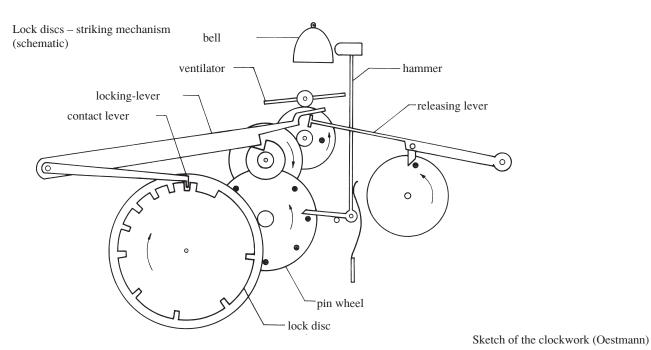
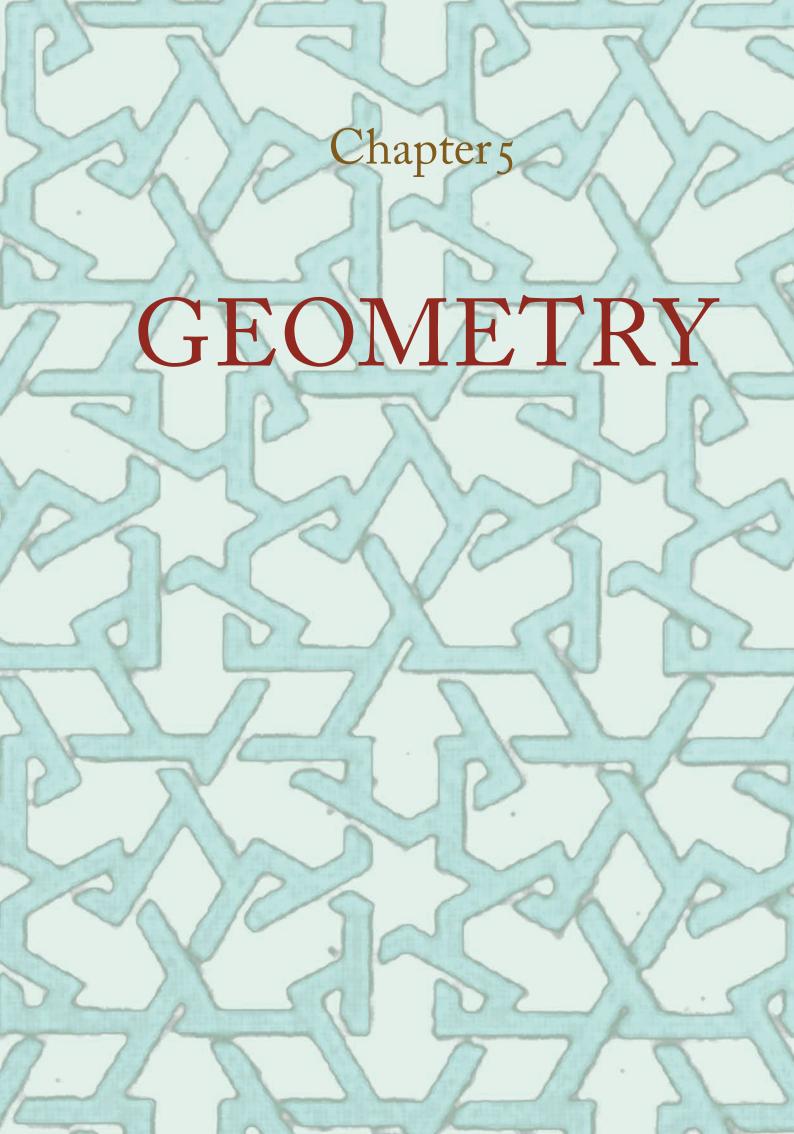



Fig. Spiral spring etc. of Taqīyaddīn, after Tekeli, p. 28.

b). Brass, steel, wire ropes. Spring mechanism with key. Height 50 cm. (Inventory No. 3.14)

Lock discs – striking mechanism (schematic)

bell

ventilator

hammer

locking-lever

releasing lever

contact lever

pin wheel

lock disc

Sketch of the clockwork (Oestmann)

Chapter 5

GEOMETRY

Introduction

The history of the origin of this branch of mathematics (which was called at a time unknown to us *handasa* or *ʿilm al-handasa*) in the Arab-Islamic world is more difficult to trace than that of arithmetic and algebra. We may perhaps assume that in this field even knowledge disseminated more or less in pre-Islamic und early Islamic times in the neighbouring cultures also fell on fertile ground in the Islamic world through the activities of the representatives of those cultures. This assumption is supported by a report by the historian al-Azraqī (1st half of the 3rd/9th c.), who preserved for us a sketch of the Kaʿba in Mecca which the historian ʿAbdalmalik b. Ǧuraiǧ (d. 150/767) is said to have drawn with his own hand in the form of a *tarbīʿ* (square).[1]

Converted and non-converted Greeks, Persians and Syrians are among the first representatives through whom elementary geometrical knowledge reached Damascus and Baghdad, the capitals of the Umayyads and the Abbasids. It should also be remembered that the famous astronomical-mathematical book of the Indians, the *Brāhma Sphuṭa-Siddhānta*, translated into Arabic in 156/772 at the instance of Caliph al-Manṣūr,[2] contains a section on geometry and trigonometry. The terminology required for the translation must already have been to some extent familiar to the translator, Ibrāhīm b. Ḥabīb (or Muḥammad b. Ḥabīb) al-Fazārī. Subsequently, he and his contemporary Yaʿqūb b. Ṭāriq were in a position to publish their own mathematical and astronomical works in Arabic.[3]

The earliest title of an Arabic geometrical book is by the natural philosopher Ǧābir b. Ḥaiyān (2nd half of the 2nd/8th c.) and is called *Taʿālīm al-handasa*,[4] "Lessons in Geometry." Even in his books on chemistry Ǧābir recommends that his reader should acquire knowledge in geometry in addition to other sciences.[5] He conceives the universe as having a geometrical form, and in the advanced organisation of the beings of this world numbers as points form lines, lines form areas and areas form bodies. He even expresses the qualitative natures (elements, humours) geometrically. Thus, for instance, in animals warmth is said to be present in cubic form, whereas cold, humidity and dryness are said to be present in quadratic form.[6] Ǧābir quotes Euclid's book and is said to have also written a commentary on it.[7] Euclid's book of the *Elements* was translated with the title *Kitāb al-Uṣūl* or *Kitāb al-Usṭuqusāt* during the reign of Hārūn ar-Rašīd (170/786-193/809), and then under al-Ma'mūn (198/813-218/833) it was translated once more or rather revised by the same translator al-Ḥaǧǧāǧ b. Yūsuf (apart from a later translation by Isḥāq b. Ḥunain in the 2nd half of the 3rd/9th century).[8] The translation of the *Elements* of Euclid was followed by translations of the books by Archimedes,[9] Apollonius of Pergae,[10] Menelaos,[11] Ptolemy[12] and others. From the point of view of the history of science, it should be noted that these were not occasional translations, but the fruit of a maturity in the treatment of the material that had already been attained, which served for the gratification of the demands of an intellectually curious society for the knowledge of the preceding foreign cultures, particularly the Greeks, and these translations were part of an intellectual current that was led and supported by rulers and statesmen. What was characteristic of this phenomenon was also the fact that, immediately after the translations, the Arabs began with commentaries, additions and enlargements, in fact even with attempts at corrections of the translated works. The circle of participants in these tasks quickly spread beyond the [**126**] boundaries of Baghdad and gradually extended almost from the easternmost to the westernmost parts of the Islamic world. The activities lasted for centuries, in some regions even until the 9th/15th century, and certainly did not come to an end as early as is often assumed and averred.

[1] Azraqī, *Aḫbār Makka*, Leipzig 1858, pp. 111–112; v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 5, p. 24.
[2] F. Sezgin, op. cit., vol. 5, pp. 199-200.
[3] ibid., vol. 5, p. 216–218; vol. 6, pp. 122–127.
[4] ibid., vol. 5, p. 225.
[5] ibid., vol. 5, p. 221.
[6] v. Paul Kraus, *Jābir ibn Ḥayyān. Contribution à l'histoire des idées scientifiques dans l'Islam*, vol. 2, Cairo 1942 (reprint: Natural Sciences in Islam, vol. 68, Frankfurt 2002), pp. 178-179; F. Sezgin, op. cit., vol. 5, p. 223.
[7] F. Sezgin, op. cit., vol. 5, pp. 225.
[8] ibid., vol. 5, pp. 103–104.
[9] ibid., vol. 5, pp. 121–136.
[10] ibid., vol. 5, pp. 136–143.
[11] ibid., vol. 5, pp. 158–164.
[12] ibid., vol. 5, pp. 166–174.

In the following I shall attempt, on the basis of recent results of research, to give an idea of some important achievements of Arab-Islamic scholars in the field of geometry.

Theory of Parallels

Let us begin with the results achieved by the redaction of Euclid's *Elements*. Al-ʿAbbās b. Saʿīd al-Ǧauharī (active under al-Maʾmūn in the first third of the 3rd/9th century), the second commentator of the Elements, after writing a commentary on the entire book, felt the need to undertake a revision or improvement (*iṣlāḥ*) of the same and to contribute additions (*ziyādāt*) as well.[13] The extant portion of his attempt at improvement pertains to Euclid's fifth postulate, which runs: "(It is postulated) that, when a straight line, while intersecting two straight lines, causes the inside angles resulting on the same side to be together smaller than two right angles, then the two straight lines upon extension to infinity meet on that side, on which the angles lie which together are smaller than two right angles." [14]
For this postulate (*šakl*) al-Ǧauharī proposes the following form: "If the adjacent angles are equal at the intersection of two straight lines by any third one, then such straight lines are parallel and equidistant to one another."[15] The postulates formulated by al-Ǧauharī for his attempt at proof are quite remarkable, even if imperfect. A similar proof was suggested by the French mathematician A. M. Legendre in 1800.[16]
With his attempt at perfecting Euclid's 5th postulate al-Ǧauharī entered the circle of those Arab-Islamic mathematicians who were moving in the course of centuries towards the threshold of non-Euclidian geometry. Further steps in this direction were taken by al-Faḍl b. Ḥātim an-Nayrīzī[17] (3rd/9th c.) and Ṯābit b. Qurra[18] (d. 288/901). In the first half of the 5th/11th century Ibn al-Haiṯam[19] endeavoured to elucidate all the postulates of Euclid in a voluminous book. This *Šarḥ muṣādarāt Uqlīdis* [20] "gives us an insight into the basic discussions which Euclid's work and the attempts at understanding it, its critique and substantiation caused among the Arabs."[21] Ibn al-Haiṯam supplemented this work with another one which he called *Ḥall šukūk Kitāb Uqlīdis fi l-Uṣūl* [22] ("Solution of Doubts in Euclid's Book of the Elements ").
Ibn al-Haiṯam attempts to prove the theory of parallels formulated in the 5th postulate by a principle of motion which amounts to the assumption that lines of constant distance to a straight line are again straight lines. A similar approach was taken by mathematicians in Europe in the 18th century. Johann Heinrich Lambert (d. 1777) was one of them.[23]
About half a century after Ibn al-Haiṯam, the same subject was dealt with by ʿUmar al-Ḫaiyām, the great mathematician, astronomer, philosopher and poet. His philosophical attitude towards mathematical concepts shows particularly in the law of proportions, parallels and the concept of numbers. He wrote a [**127**] commentary in three parts on the postulates and the difficult passages in Euclid's *Elements*, the last two parts dealing with the law of proportions, the first one with the parallel postulate. In his theory of parallels al-Ḫaiyām criticises his predecessor Ibn al-Haiṯam for using motion as a proof in geometry. Al-Ḫaiyām "introduces a rectangle with two right angles on the base line as well as with equi-lateral sides and examines three hypotheses about its remaining two angles, which are equal to one another. This rectangle was also examined in the 18th century by the Italian mathematician G. Saccheri and is therefore often named after him."[24]

[13] F. Sezgin, op. cit., vol. 5, pp. 243–244.
[14] Translated from *Die Elemente von Euklid*. Aus dem Griechischen übersetzt und herausgegeben von Clemens Thaer, reprint Frankfurt 1997, p. 3.
[15] A. P. Juschkewitsch, *Geschichte der Mathematik im Mittelalter*, Leipzig and Basle 1964, p. 278; Ḫ. Ǧāwīš, *Naẓarīyat al-mutawāziyāt fi l-handasa al-islāmīya*, Tunis 1988, p. 43; K. Jaouiche (= Ḫ. Ǧāwīš), *La théorie des parallèles en pays d'Islam. Contribution à la préhistoire des géométries non-euclidiennes*, Paris 1986, p. 137.
[16] Juschkewitsch, op. cit., p. 278; K. Jaouiche, *La théorie des parallèles*, op. cit., p. 43.
[17] F. Sezgin, op. cit., vol. 5. pp. 283-285.
[18] Juschkewitsch, op. cit., pp. 279-280; K. Jaouiche, *La théorie des parallèles*, op. cit., pp. 45-46.
[19] F. Sezgin, op. cit., vol. 5, pp. 358-374.
[20] Facs. ed. (with a preface by Matthias Schramm) Institut für Geschichte der Arabisch-Islamischen Wissenschaften, Frankfurt 2000.
[21] Translated from M. Schramm's preface to *Šarḥ muṣādarāt Uqlīdis*, p.7.
[22] Facs. ed. Institut für Geschichte der Arabisch-Islamischen Wissenschaften, Frankfurt 1985.
[23] Juschkewitsch, op. cit., pp. 280-281.
[24] A. P. Juschkewitsch and B. A. Rosenfeld, *Die Mathematik der Länder des Ostens im Mittelalter*, Berlin 1963, p. 150; D. E. Smith, *Euclid, Omar Khayyâm and Saccheri*, in: Scripta Mathematica (New York) 2/1935/5-10; K. Jaouiche, *On the Fecundity of Mathematics from Omar Khayyam to G. Saccheri*, in: Diogenes (Oxford) 57/1967/83-100; F. Sezgin, op. cit., vol.

The polymath Naṣīraddīn aṭ-Ṭūsī (d. 672/1274) also dealt with the parallel postulate at length. In his treatise devoted to the subject, *ar-Risāla aš-šāfiya ʿan aš-šakk fi l-ḫuṭūṭ al-mutawāziya*[25] he subjects the respective views of his predecessors to a critical appraisal, during which he proceeds almost like al-Ǧauharī and al-Ḫaiyām. In his revision (*Taḥrīr*) of Euclid's book (which I do not currently have at my disposal) he is said[26] to have replaced Euclid's postulate by his own: "If two straight lines, lying in the same plane, diverge from one another in one direction, then they cannot meet in that direction, unless they intersect."

However, it was not these two books but another one whereby the name of Naṣīraddīn aṭ-Ṭūsī attracted so much attention in the history of the parallel postulate. It is the *Taḥrīr al-Uṣūl li-Uqlīdis*, which was published under the name of aṭ-Ṭūsī in the year 1594 by Giovan Battista Raimondi in the Typographia Medicea. Today it is established that the book is not identical with Naṣīraddīn aṭ-Ṭūsī's *Taḥrīr*. I have not been able to settle the question of its authorship and hope that future research will succeed in doing so. Incidentally the possibility should not be excluded that we are dealing here with another work by aṭ-Ṭūsī. In any case, it does not seem to be less competent than his other works. The book found wide dissemination in Europe, since it was translated into Latin by the Oxford orientalist Edward Pococke (1604-1691) soon after its publication. Its earliest impact was seen in the case of the English mathematician John Wallis (1616-1703). The argumentation of the Arabic book "conformed to a large extent with Wallis's ideas. He wanted to replace Euclid's postulate with the assumption of similar figures, and for this Naṣīraddīn's ideas served him as an excellent instrument. Wallis declared this, as he himself informs us, on 7. 2. 1651 (Old Style) in the course of his public lectures in Oxford. Later he had this lecture published in his works together with the Latin translation of Naṣīraddīn's remarks on the 28th postulate of the first book of the *Elements*."[27]

"Via the Latin translation published by Wallis, Naṣīraddīn's views on the theory of parallels were accessible to all mathematicians. Among them was the highly gifted Jesuit Girolamo Saccheri (1667-1733), who took the next decisive step in the theory of parallels. In his *Euclides ab omni naevo vindicatus*, which appeared in Milan in 1733, he discussed Naṣīraddīn thoroughly … In fact, Saccheri started exactly at that point which Naṣīraddīn had reached. He thereby initiated the development which then led to realising the independence of the parallel postulate from the remaining postulates and finally to non-Euclidian geometry."[28]

[**128**] After these remarks on the theory of parallels among the mathematicians of the Arabic-Islamic world, we may now mention some of their achievements in geometrical construction models and algebraic geometry.

Algebraic Geometry

Within some fifty years after its first translation Euclid's book of the *Elements* seems to have been completely assimilated in the Arabic-Islamic world. The terminological difficulties were almost fully overcome. Moreover, even before the middle of the 3rd/9th century important works by Archimedes, Apollonius and Menelaos were available in Arabic translations, and their contents became widely known. Investigations to date of the extant Arabic geometrical texts from that period testify not only to their authors' masterly treatment of the works of the Greek masters, but also to some awareness of their own creativity. A clear idea of this attitude is provided by the three sons of Mūsā b. Šākir (Banū Mūsā), who were active in the first half of the 3rd/9th century in Baghdad. Their works testify to the ability to discuss the work of their predecessors objectively and creatively, where the determining factor in my opinion is not how much has been accomplished in this process. In their book on geometry they claim to have found a new solution for the trisection of the angle. Here they rely on a

5, pp. 51-52.

[25] About the MSS, v. F. Sezgin, op. cit., vol. 5, p. 113; Ed. Hyderabad 1940 (reprint in: Islamic Mathematics and Astronomy, vol. 49, Frankfurt 1998, pp. 363-434); Ḫ. Ǧāwīš, *Naẓarīyat al-mutawāziyāt*, op. cit., pp. 159-203.

[26] A. P. Juschkewitsch, op. cit., p. 285.

[27] v. J. Wallis, *Opera mathematica*, vol. 2, Oxford 1693, pp. 669-673.

[28] These statements on the book, which was published in Rome, were written by my friend Matthias Schramm, who studied the book at my request in 1987 and wrote a preface to a reprint that was to be published as one of the publications of our Institute. I am pleased to be able to take this opportunity to make at least a small part of his excellent preface available to the reader. At that time we had to postpone the planned reprint and were not able to publish the book until ten years later (without the preface).

curve which in the history of mathematics came to be known later, in a more developed form, as "Pascal's limaçon". When we assess their achievement in such a case, their attitude is more important than their objective success. Mūsā's sons also undertook the mensuration of the circle after the method developed by Archimedes, but chose a different way of presentation. They attempted "to distance themselves as far as possible from their Greek models by using a different method of proof and by choosing different letters of the alphabet."[29]

The outstanding features of the beginning of the period of independent creativity, not only in the field of geometry, become evident in the extant fragments of the works of Muḥammad b. ʿĪsā al-Māhānī[30] (d. ca. 275/888), a younger contemporary of Mūsā's sons. What is relevant for our subject is al-Māhānī's attempt at solving the question raised by Archimedes: how to divide a given sphere by a plane into two segments which have a certain ratio. He tried to solve the problem with a cubic equation but, as ʿUmar al-Ḫaiyām[31] later confirmed, did not succeed.[32] In this connection al-Ḫaiyām further reports that al-Māhānī's successor, Abū Ğaʾfar al-Ḫāzin (Muḥammad b. al-Ḥusain), who was active in the first part of the 4th/10th century, succeeded in solving a cubic equation; he declared that the conic sections were sufficient for finding the roots of cubic equations.[33]

About half a century after Abū Ğaʿfar al-Ḫāzin, Ibn al-Haiṯam also dealt with the problem posed by Archimedes. He too reduced it to a cubic equation, solving it by means of conic sections.[34] A further step in the field of algebraic geometry was taken by Ibn al-Haiṯam in his book of optics (*Kitāb al-Manāẓir*), with the solution to the problem which he had set himself, viz. to find the point of reṭection of a spherical curved mirror from which the image of an object at a given place is reṭected into the eye which is likewise situated at a given place. The question was treated by Ibn al-Haiṯam geometrically and solved with an equation of the fourth degree.[35] In another chapter of the present volume (see below, p. 187) it will be shown [**129**] that Ibn al-Haiṯam's problem occupied European scholars from the 13th to the 19th centuries as *Problema Alhazeni*. It is unfortunate that the historian of mathematics Jean Étienne Montucla doubted that Ibn al-Haiṯam was able to solve this problem himself when he wrote: "One would even have to rank him with the scholars of geometry of a higher order if it was certain that he was also the originator of the solution of the problem that he had posed."[36]

The extant treatises of Abu l-Ğūd Muḥammad b. al-Laiṯ,[37] a contemporary of Ibn al-Haiṯam, show the rapid advances made in the field of mathematics, where conic sections were used for the solutions of problems when the use of a circle and straight lines is not sufficient. Among the problems solved by Abu l-Ğūd in this manner there are also some which al-Bīrūnī posed to him.[38] His results create the impression that to some extent he can be called the precursor of ʿUmar al-Ḫaiyām in the development of a general law of cubic equations. Here we may add that a solution has come down to us for the problem of constructing a trapezium with three sides of length 10 and area 90. The anonymous mathematician to whom we owe the result probably lived in the second half of the 5th/11th century. He solved the resulting equation $x^4 + 2000x = 20x^3 + 1900$ by the intersection of a hyperbola with a circle. It is remarkable that the author states that various mathematicians of algebra and geometry had for some time pondered over this question without having been able to solve it satisfactorily.[39]

Algebraic geometry was substantially expanded by the constructions and attempts at construction of the regular heptagon which began to appear in the

[29] H. Suter, *Über die Geometrie der Söhne des Mûsâ ben Schâkir*, in: Bibliotheca Mathematica (Stockholm) 3rd series, 3/1902/259-272, esp. p. 272 (reprint in: Islamic Mathematics and Astronomy, vol. 76, pp. 137-150, esp. p. 150); F. Sezgin, op. cit., pp. 248-249.

[30] F. Sezgin, op. cit., vol. 5, pp. 260-262; vol. 6, pp. 155-156.

[31] *Maqāla fi l-ğabr wa-l-muqābala*, ed. Fr. Woepcke in: *L'algèbre d'Omar Alkhayyâmî*, Paris 1851, Arabic p. 2, French p. 96 (reprint in: Islamic Mathematics and Astronomy, vol. 45, pp. 1-206, esp. pp. 120, 203).

[32] v. F. Sezgin, op. cit., vol. 5, pp. 35, 260, after J. P. Hogendijk, *The Works of al-Māhānī*, text of a lecture delivered at Teheran (Utrecht, 13 pp.), p. 9.

[33] F. Sezgin, op. cit., vol. 5, p. 298.

[34] ibid, vol. 5, p. 359.

[35] ibid, vol. 5, pp. 48, 359.

[36] *Histoire des mathématiques*, vol. 1, Paris 1758, pp. 359-360; M. Schramm, *Ibn al-Haythams Stellung in der Geschichte der Wissenschaften*, in: Fikrun wa Fann (Hamburg) 3/1965,6/Arabic pp. 85-65, esp. p.67.

[37] F. Sezgin, op. cit., vol. 5, pp. 353-355.

[38] ibid, pp. 353, 354; v. also J. P. Hogendijk, *Greek and Arabic Constructions of the Regular Heptagon*, in: Archive for History of Exact Sciences (Berlin) 30/1984/197-330, esp. pp. 223-224, 244-256, 267.

[39] F. Woepcke, *L'algèbre d'Omar Alkhayyâmî*, op. cit., pp. 115-116 (reprint op. cit., pp. 138-139).

second half of the 4th/10th century. Not in all cases, but in some, the problem is solved by means of conic sections.[40]

Sufficient advances had been made by the second half of the 5th/11th century for one of the greatest mathematicians of the time, ʿUmar al-Ḫaiyām, to be able to formulate a general law of cubic equations. His treatise, written for this purpose, *Risāla fi l-Barāhīn ʿalā masāʾil al-ǧabr wa-l-muqābala*, was edited in the middle of the 19th century and translated into French, with its revolutionary role in the history of mathematics being convincingly demonstrated in an excellent study by Franz Woepcke. In his text, in which algebra is strictly differentiated from arithmetic, al-Ḫaiyām says: "The algebraic solutions are executed with the help of an equation, i.e. using the familiar method of equating different potencies."[41] For equations containing numbers, objects, or sides and squares, that is to say those which do not go beyond the second order, the numerical solution follows from the geometrical, for which recourse has to be made to the *Elements* and the *Data* of Euclid. The idea of the inadequacy of the circle and straight lines in cubic equations was voiced for the first time by ʿUmar Ḫaiyām; it was not formulated again in Europe until 1637 by René Descartes, being finally established by P. L. Wantzel (1837).[42]

[**130**] ʿUmar al-Ḫaiyām divides equations into 25 types. One of those is linear, i.e. a simple equation, five are quadratic, that is to say equations of the second degree, five more are cubic (third degree) but can be reduced to quadratic equations, and the remaining 14 are of the type of cubic equations which can be constructed and solved by means of conic sections.

In two cases he applies the geometrical method of construction to numerical equations. What is even more important than the individual results achieved is their methodological aspect: al-Ḫaiyām separates the coordinate systems of the old law of conic sections from the individual conic section by using one and the same system for several conic sections; and it was he who clearly recognised in this connection the advantages of rectangular systems, which are unjustly named after Descartes.[43]

ʿUmar al-Ḫaiyām's book, like many works from the eastern part of the Arabic-Islamic world, remained unknown in the West. This fact was expressed by J. Tropfke[44] in 1937 as follows: "Unfortunately, the more detailed knowledge of his excellent work was withheld from the Occident until quite recently. Fermat (ca. 1637), Descartes (1637), van Schooten (1659), E. Halley (1687) and others had to reinvent similar constructions."

The next successors of al-Ḫaiyām known to us in the treatment of cubic equations were Šarafaddīn al-Muẓaffar b. Muḥammad aṭ-Ṭūsī[45] (6th/12th c.) and Ġiyāṯaddīn Ǧamšīd b. Masʿūd al-Kāšī (d. 840/1436). In the fifth chapter of his *Miftāḥ al-ḥisāb* the latter points out that he was the first to find the solution for 70 equations of the fourth degree.[46]

Trigonometry

It is likely that the trigonometric knowledge of the Indians reached the Arabic-Islamic world via early Muslim representatives from the former Persian-Sassanid centres of science even before the main work of the Indians on astronomy and mathematics, the *Brāhma Sphuṭa-Siddhānta*, was translated into Arabic at the instance of Caliph al-Manṣūr in 156/772. In comparison to the Greeks, an important step forward was made in India in the field of trigonometry by replacing the chord by the sine, i.e. the half chord of the double angle was used instead of the full chord, and this, besides the Greek approaches, facilitated further development by the Arab-Islamic scholars. That the modern

[40] Y. Samplonius, *Die Konstruktion des regelmäßigen Siebenecks nach Abu Sahl al-Qûhî Waiğan ibn Rustam*, in: Janus (Leiden) 50/1963/227-249; R. Rashed, *La construction de l'heptagone régulier par Ibn-al-Haytham*, in: Journal for the History of Arabic Science (Aleppo) 3/1979/309-387; J. P. Hogendijk, *Greek and Arabic Constructions of the Regular Heptagon*, op. cit.

[41] F. Woepcke, *L'algèbre d'Omar Alkhayyâmî*, op. cit., p. 7 (reprint op. cit., p. 31).

[42] Juschkewitsch, op. cit., p. 261; A. P. Juschkewitsch and B. A. Rosenfeld, *Die Mathematik der Länder des Ostens im Mittelalter*, op. cit., p. 120; Johannes Tropfke, *Geschichte der Elementar-Mathematik*, vol. 3, 3rd ed., Berlin and Leipzig 1937, p. 125; F. Sezgin, op. cit., vol. 5, p. 50.

[43] F. Sezgin, op. cit., vol. 5, pp. 50-51; for details v. M. Schramm, *Steps towards the Idea of Function. A Comparison between Eastern and Western Science of the Middle Ages*, in: History of Science, vol. 4, Cambridge 1965, pp. 70-103, esp. p. 97.

[44] *Geschichte der Elementar-Mathematik*, op. cit., vol. 3, p. 133.

[45] An extant anonymous extract from his book on equations was edited and translated into French by R. Rashed, *Sharaf al-Dīn al-Ṭūsī, Oeuvres mathématiques. Algèbre et géométrie au XIIe siècle*, 2 vols., Paris 1986.

[46] v. F. Sezgin, op. cit., vol. 5, p. 68.

term 'sine' is a translation of the Arabic word *ǧaib* (pocket) is well known. The Arabs on their part had transcribed the Indian trigonometric term *ǧiva* (bow string) phonetically as *ǧīb*, which was then read as *ǧaib* and misunderstood by the Latin translators. In the earliest books the word *ardaǧiva* was also used for the half chord, but later the term for sine was abbreviated as ǧīb. Therefore the oldest known Arabic book on trigonometry by Yaʿqūb b. Ṭāriq (ca. 161/777) bore the title *Kitāb Taqṭīʿ kardaǧāt al-ǧīb*, i.e. "Finding of the Sine of an Arc of the Circle."[47]
To complete the picture we should mention that the translation of the *Siddhānta* not only led to the knowledge of the term and function of the sine but also of the cosine and of a small sine table being disseminated in the Arabic-Islamic world.
The trigonometric knowledge of the Greeks (which was not unconnected to their Chaldean predecessors[48]), which goes back mainly to Hipparchus (2nd c. B.C.) and Menelaos (2nd half of the 1st c. B.C.), reached the Arabic-Islamic mathematicians and astronomers with the first translation of Ptolemy's *Almagest*[49] [**131**] in the last quarter of the 2nd/8th century. The Greek astronomer used "the size of the chord which belongs to the double angle functioning as the angle from the centre of the circle. With the size of the angle from the centre the size of the chord changes; and for this variability Hipparchus had compiled a table."[50]
The basic ideas of the Greeks on trigonometry became, after the translation into Arabic of the works of Menelaos and Ptolemy, very fruitful for the development of the next 500 years as a result of the former's theorem of the complete quadrilateral and the latter's transversal theorem.
The earliest impetus known to us for a creative interest of Arabic-Islamic mathematicians in the transversal theorem of Menelaos–Ptolemy doubtless came from al-Māhānī (ca. 250/865), the first reviser of the spherics. While determining the azimuth, he applied to the triangle a theorem which was equivalent to the spherical cosine theorem.[51]
P. Luckey,[52] who discovered this theorem in al-Māhānī's commentary on the spherics of Menelaos, could thus conclusively refute the assertion by J.-B. Delambre and A. von Braunmühl that Regiomontanus did not, in this respect, have any predecessor among the Arabs.[53]
It is one of the stages of development in the history of trigonometry that in the second half of the 3rd/9th century the concept and the function of the tangent can be discerned in the works of the astronomer and mathematician Ḥabaš al-Ḥāsib.[54] He, "in his table work, first put together the cosecants, which he calls shadow-diameters (*quṭr aẓ-ẓill*), in a table of 1° - 90°."[55] In 1900, A. von Braunmühl,[56] who did not yet know the book (*az-Zīǧ*) by Ḥabaš, considered Abu l-Wafāʾ al-Būzaǧānī[57] (d. 387 or 388/998) to be the discoverer of the tangent function. About a fifth of a century after the publication of A. von Braunmühl's book, C. Schoy[58] estab-

[47] v. ibid, vol. 5, p. 196.
[48] v. J. Tropfke, *Geschichte der Elementar-Mathematik*, 2nd ed., vol. 5, Berlin and Leipzig 1923, p. 12.
[49] For the relevant chapter v. Ptolemy, *Handbuch der Astronomie*, German translation by K. Manitius, new ed. Leipzig 1963, vol. 1, pp. 24 ff.
[50] J. Tropfke, op. cit., vol. 5, pp. 13.
[51] On the formula, v. F. Sezgin, op. cit., vol. 5, p. 261.
[52] *Beiträge zur Erforschung der arabischen Mathematik*, in: Orientalia (Rome), N.S. 17/1948/490-510, esp. p. 502 (reprint: Islamic Mathematics and Astronomy, vol. 96, Frankfurt 1998, pp. 46-66, esp. p. 58).
[53] F. Sezgin, op. cit., vol. 5, p. 159.
[54] ibid, vol. 5, pp. 275-276; vol. 6, pp. 173-175.
[55] J. Tropfke, op. cit., vol. 5, p. 29; C. Schoy, *Über den Gnomonschatten und die Schattentafeln der arabischen Astronomie. Ein Beitrag zur arabischen Trigonometrie nach unedierten arabischen Handschriften*, Hanover 1923, pp. 12, 14-15 (reprint: Islamic Mathematics and Astronomy, vol. 25, pp. 198, 200-201).
[56] *Vorlesungen über Geschichte der Trigonometrie*, vol. 1, Stuttgart 1900, pp. 54-61. Braunmühl, having evaluated trigonometrically the Almagest of Abu l-Wafāʾ by means of the material made available by Carra de Vaux (*L'Almageste d'Abû'lwéfa Albûzdjâni*, in: Journal Asiatique (Paris), 8e série, 19/1892/408-471, reprint: Islamic Mathematics and Astronomy, vol. 61, pp. 12-75), says, beginning with a quote from Abu l-Wafāʾ: "'Therefore it is clear, that, when the radius is made equal to 1, the ratio of the sine of an arc to the sine of its complement is the first shadow, and the ratio of the sine of the complement to the sine of the arc is the second shadow.' This statement cannot be emphasised strongly enough because it places Abû 'l Wafâ far beyond the Middle Ages and the Renaissance into modern times, and it is very strange that this idea of equating r = 1, although it was stated here most clearly, once again sank into total oblivion, so that up to the 18th century the radius continued to be included." (It should be noted here that equating r = 1 was normal procedure for Arab-Islamic mathematicians.) "With this introduction of the 6 trigonometric functions by Abû'l Wafâ, trigonometry of the plane rectangular triangle was perfected at a stroke, such that it acquired quite a modern character."
[57] v. F. Sezgin, op. cit., vol. 5, pp. 321-325; vol. 6, pp. 222-224.
[58] *Abhandlung von al-Faḍl b. Ḥâtim an-Nairîzî: Über die Richtung der Qibla*, in: Sitzungsberichte der Bayerischen Akademie der Wissenschaften. Mathematisch-physikalische Klasse (Munich) 1922, pp. 55-68, esp. p. 56 (reprint: Islamic Geography, vol. 18, Frankfurt 1992, pp. 177-190, esp. p. 178).

lished that al-Faḍl b. Ḥātim an-Nairīzī[59] (died at the beginning of the 4th/10h c.) was the precursor of Abu l-Wafāʾ in the knowledge of the shadow rule. As his successor Schoy considered Ibn al-Haiṯam[60] (d. 432/1041) who used the cotangent theorem of spherical trigonometry for finding the direction of the *qibla*.[61] Ibn al-Haiṯam found the angle of deviation of any given place from Mecca as

[132] $$\cot g\,\alpha = \frac{\sin \varphi_1 \cdot \cos \lambda - \cos \varphi_1 \cdot \tan g\,\varphi_2}{\sin \lambda}.$$

where φ_2 is the latitude of Mecca, φ_1 the latitude of the place and λ the difference in longitude between the two.

After these remarks on the development of the tangent as a trigonometric function, which was still unknown to the Greeks and the Indians, I now turn to the development which the Menelaic-Ptolemaic transversal theorem underwent among the Arab-Islamic mathematicians and astronomers. Here we deal with the two formulae

I. AE : EB = (AU : UD) · (GD : GB);
II. AB : EB = (AD : UD) · (GU : GE)

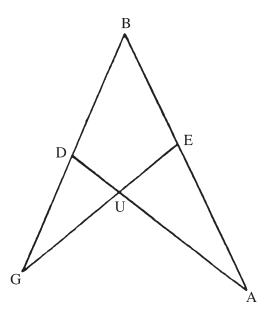



Fig. 1 (A. Björnbo)

“If the straight lines of fig. 1 are replaced by arcs of the largest circles in the sphere which, however, are smaller than 180° (fig. 2), you arrive at the corresponding theorems for the sines of the arcs of the circle.”[62]

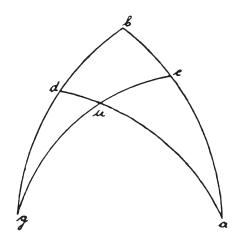



Fig. 2 (A. Björnbo)

Muḥammad b. Mūsā, the eldest of the three sons of Mūsā b. Šākir, had already dealt with the problem in the first half of the 3rd/9th century. Yet it is Ṯābit b. Qurra (2nd half of the 3rd/9th c.) who is the first to be mentioned by Arabic-Islamic mathematicians when this question is discussed. At least in his treatise *Kitāb fi š-Šakl al-mulaqqab bi-l-qaṭṭāʿ* he concerned himself seriously with the transversal theorem. However, Ṯābit’s treatise,[63] which meanwhile is examined in detail and was disseminated in the occidental Middle Ages in at least two translations, does not contain anything substantially new. On the other hand, Abū Naṣr b. ʿIrāq (2nd half of the 4th/10th c.) and Naṣīraddīn aṭ-Ṭūsī (d. 672/1274), who knew the history of the theorem well and themselves made significant contributions to its advancement, stress “that Ṯābit had also formulated a theorem which made the transversal theorem superfluous, but that in its application the knowledge of the compound ratios had to be as-

[59] v. F. Sezgin, op. cit., vol. 5, pp. 283-285; vol. 6, pp. 191-192.
[60] ibid, vol. 5, p. 362.
[61] C. Schoy, *Abhandlung des al-Ḥasan ibn al-Ḥasan ibn al-Haiṯam (Alhazen) über die Bestimmung der Richtung der Qibla*, in: Zeitschrift der Deutschen Morgenländischen Gesellschaft (Leipzig) 75/1921/242-253, esp. pp. 243-244 (reprint: Islamic Geography, vol. 18, pp. 155-166, esp. pp. 156-157).

[62] Axel Björnbo, *Thabits Werk über den Transversalensatz (liber de figura sectore)*. With annotations by Heinrich Suter. Edited Ş by H. Bürger and K. Kohl, Erlangen 1924, pp. 1-2 (reprint: Islamic Mathematics and Astronomy, vol. 21, Frankfurt 1997, pp. 215-311, esp. pp. 221-222).
[63] The most recent study on this is by Richard Lorch, *Thābit ibn Qurra. On the Sector-Figure and Related Texts*. Edited with Translation and Commentary, Frankfurt 2001. (Islamic Mathematics and Astronomy, vol. 108).

sumed."[64] Moreover, it follows from a quotation by Naṣīraddīn that Ṯābit replaces the chord of the double arc, which formed the basis of calculation for Menelaos and [**133**] Ptolemy, with the sine function. H. Suter took the view that the extant redaction of the treatise on the transversal theorem dates from Ṯābit's youth and that there must be another work by him in existence.[65]

The attempts at improving and enlarging the trigonometric knowledge inherited from the Greeks and Indians were continued after the 3rd/9th century with full intensity. The extent of the efforts of the many scholars involved was described more vividly by al-Bīrūnī than by any other author, in his *Taḥdīd nihāyāt al-amākin li-taṣḥīḥ masāfāt al-masākin*, [66] which can be considered a fundamental work of mathematical geography. As a consequence of the intensive work and the excellent conditions for supporting this complementary science, a turning point in the history of spherical trigonometry was reached towards the end of the 4th/10th century. It is astonishing and can only be understood as a sign of the intellectual maturity of the time that three scholars at different places were almost simultaneously convinced of having achieved the decisive breakthrough for the calculation of the sides and angles of the spherical triangle. They were Abu l-Wafāʾ al-Būzaǧānī, Ḥāmid b. al-Ḫiḍr al-Ḫuǧandī and Abū Naṣr Manṣūr b. ʿAlī Ibn ʿIrāq. We hear about this from some works by al-Bīrūnī, particularly from his *Maqālīd ʿilm al-haiʾa*,[67] from the anonymous *Ǧāmiʿ qawānīn ʿilm al-haiʾa* (5th/11th c.)[68] and from the book on *aš-Šakl al-qaṭṭāʿ* [69] by Naṣīraddīn aṭ-Ṭūsī (672/1274). The importance for the history of mathematics of the achievements of the three scholars and the question of the contribution of each individual member was excellently discussed by Paul Luckey in 1940. Although he could not yet use the important book *Maqālīd ʿilm al-haiʾa*, which was only discovered later, his description, given on the basis of the aforementioned anonymous *Ǧāmiʿ* and entitled *Zur Entstehung der Kugeldreiecksrechnung*,[70] retains its value even today, remaining unsurpassed. Luckey writes: "But a truly revolutionising, independent achievement of the mathematicians from the world of Islam is that around the year 1000 formulae were produced on the functions of sides and angles in the spherical triangle, particularly the spherical sine theorem. The cumbersome complete quadrilateral of Menelaos' theorem was replaced by the triangle and the 6 parts in Menelaos' formula by only 4. Here we witness the birth of the true spherical 'trigonometry' or spherical calculation of the triangle. The bare spherical triangle is a simpler figure than the complete quadrilateral, and yet this bare triangle has 6 elements, the three sides and the three angles, and the objective can be to find a formula between four each of these elements." "Here all the prospects for modern spherical trigonometry are set forth and at the same time the prospects for the modern geometrical principles of duality and reciprocity, since a natural path now leads to the polar triangle. The problem, not yet envisaged by the Greeks, of calculating the sides from the angles of a spherical triangle, suggests the construction of the arcs equal to 'the sum' of the given angles on the sphere in the manner of the Greeks, as was indicated above. However, these arcs, lengthened sufficiently, form the polar triangle. In fact the 'Arabs' arrived at the polar triangle via this problem. This is apparent even before aṭ-Ṭūsī (pp. Arabic 152-153 = pp. 197-198) …"[71]

"The transformation from the ancient to the modern spherical calculation has, accordingly, as its first decisive characteristic the more or less conscious decision of also taking into account, besides the sines of the arcs, [**134**] the sines of the angles of the spherical figures and of finding a method of working with the sines of these angles—a method which no longer always describes, as for Ptolemy, the arc which is the measure for this angle. Consequently, in the field of terminological research the ques-

[64] A. Björnbo, *Thabits Werk* …, op. cit., p. 61 (reprint, op. cit., p. 281).

[65] A. Björnbo, op. cit., p. 5 (reprint, op. cit., p. 225); F. Sezgin, op. cit., vol. 5, p. 37.

[66] Ed. P. Bulgakov, Cairo 1962 (reprint: Islamic Geography, vol. 25, Frankfurt 1992); English translation Jamil Ali, *The Determination of the Coordinates of Positions for the Correction of Distances between Cities*, Beirut 1967 (reprint: Islamic Geography, vol. 26, Frankfurt 1992); commentary by E. S. Kennedy, *A Commentary upon Bīrūnī's Kitāb Taḥdīd al-Amākin*, Beirut 1973 (reprint: Islamic Geography, vol. 27, Frankfurt 1992).

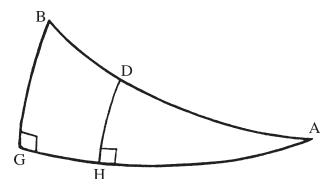
[67] v. F. Sezgin, op. cit., vol. 6, pp. 266-267; edited and translated into French by Marie-Thérèse Debarnot, Damascus 1985.

[68] v. F. Sezgin, op. cit., vol. 6, pp. 64-65.

[69] Edited and translated into French by Alexandre Pacha Carathéodory, *Traité du quadrilatère*, Istanbul 1891 (reprint: Islamic Mathematics and Astronomy, vol. 47, Frankfurt 1998).

[70] In: Deutsche Mathematik (Leipzig) 5/1940/405-446 (reprint: Islamic Mathematics and Astronomy, vol. 77, Frankfurt 1998, pp. 137-178).

[71] P. Luckey, *Zur Entstehung der Kugeldreiecksrechnung*, op. cit., p. 412 (reprint, op. cit., p. 144).

tion arises: when and where are the sines of angles purely and simply discussed for the first time in theorems on spherical figures in addition to the sines of arcs?"

"In this connection the second decisive criterion for the breakthrough of the new spherical calculation is the question: Are triangles used?"

"First and most importantly it would be useful, I think, to examine how, with regard to these two criteria, those men behave who were designated the discoverers of the spherical sine theorem by a competent contemporary. It is well known that according to the testimony of al-Bīrūnī the astronomers Abu 'l-Wafā', Abū Naṣr and al-Ḫuǧandī contend for the honour of having discovered this fundamental theorem."[72]

In an extant treatise[73] dedicated to the spherical sine theorem and its applications, Abū Naṣr contests Abu l-Wafā's assertion that he, Abū Naṣr, was still working with the old transversal theorem. Abū Naṣr defends himself "by saying that in the 17th theorem of the 2nd paragraph of his treatise on azimuths, he had introduced the spherical sine theorem, although only for a rectangular spherical triangle, since within the scope of that treatise he had had no reason to proceed further… In any case, Abū Naṣr does not dispute that Abu 'l-Wafā' before him proved and probably also used the spherical sine theorem for any triangle in a published treatise, viz. his Almagest. This accords well with al-Bīrūnī's explanation, passed on by aṭ-Ṭūsī, that priority should go to Abū Naṣr because he applied this rule to all cases. It speaks for the reverence of the pupil when he gives precedence to his teacher before others. But can it be recognised as a criterion for the priority of the discovery of a theorem that someone was the first to apply this theorem to all cases? Rather, does this statement by al-Bīrūnī not contain, between the lines, the admission that his teacher Abū Naṣr cannot claim the true priority of the discovery, namely the priority of time?"[74]

The origin of the nomenclature of the theorem has not yet been established beyond doubt.[75] In German it is usually rendered as the "theorem replacing the transversal theorem," although in my view it should more correctly be called the "theorem making the transversal theorem redundant." According to al-Bīrūnī[76] the name was coined by Kūšyār b. Labbān[77] (2nd half of the 4th/10th c.). In the Kitāb *aš-Šakl al-qaṭṭāʿ* Naṣīraddīn aṭ-Ṭūsī[78] "reserved the word 'substitute theorem' for the spherical sine theorem, whereas for the new theorems taken collectively, that is to say for this substitute theorem, its appendages and the tangent rule, he used the collective expression 'the elements taking the place of the transversal theorem' (*uṣūl taqūm ... maqām aš-šakl al-qaṭṭāʿ*)."[79]

Luckey[80] translates from the anonymous *Ǧāmiʿ* the addition to a proof by Abū Naṣr as follows:

[**135**] "*When AB* (see fig.) *is a quarter circle, then BG is the measure (qadr) of the angle BAG, and the sine of the quarter circle AB is the half-measure BH, which is equal to the sine of the right angle AHD. Hence the ratio of the sine of AD to the sine of DH is equal to the ratio of the sine of the angle AHD* {*,which is equal to the sine of AB*} *to the sine of the angle HAD* {*, i.e. to the sine of BG* …}. When the portions added by the author as explanation are removed, which I (Luckey says) put in braces, the great step forward towards modern trigonometry becomes apparent. Here the discussion is about the sines of angles, and the theorem is a triangle theorem, viz. the sine theorem

$$\sin AD : \sin DH = \sin AHD : \sin HAD$$

for the triangle AHD with the right angle at H."

[72] Luckey, op. cit., p. 413 (reprint p. 145).

[73] *Risāla fī Maʿrifat al-qusīy al-falakīya baʿḍihā min baʿḍ bi-ṭarīq ġair ṭarīq maʿrifatihā bi-š-šakl al-qaṭṭāʿ wa-n-nisba al-muʾallafa*, v. F. Sezgin, op. cit., vol. 5, p. 339; reprint of the 1948 Hyderabad edition: Islamic Mathematics and Astronomy, vol. 28, Frankfurt 1998.

[74] P. Luckey, op. cit., p. 416 (reprint, op. cit., p. 148).

[75] ibid, p. 419 (reprint p. 151).

[76] v. Al-Bīrūnī. *Kitāb Maqālīd ʿilm al-hayʾa. La trigonométrie sphérique chez les Arabes de l'Est à la fin du Xe siècle*. Édition et traduction by Marie-Thérèse Debarnot, Damascus 1985, p. 143.

[77] v. F. Sezgin, op. cit., vol. 5, pp. 343-345; vol. 6, pp. 246-249.

[78] *Kitāb Šakl (!) al-qaṭṭāʿ*, op. cit., text p. 89, transl. p. 115.

[79] P. Luckey, op. cit., p. 418 (reprint p. 150).

[80] ibid, p. 418 (reprint p. 150).

On the question of the chronological priority of the discovery of the sine theorem, Luckey says:[81] "From what Delambre, Carra de Vaux and Bürger and Kohl tell us about the occurence of the spherical sine theorem proper in Abu 'l-Wafā''s work, I am unable to get a definite insight into how this scholar, to whom we think we must owe the chronological priority of the discovery, comports himself with regard to the terminological formulations, particularly whether, like Abū Naṣr, he speaks directly of the sine of an angle. It remains the task of future research to clarify this …"

In the "Keys of Astronomy" (*Maqālīd ʿilm al-haiʾa*),[82] the work by al-Bīrūnī which has only been known since the 1970s and has been available since 1985 in an edition and French translation (see above, p. 134), the author gives us a kind of historical account of the preceding attempts made to clarify the theory of the four quantities of spherical astronomy, providing a clear idea of the level of knowledge attained in the east of the Islamic world. The expression *aš-šakl aẓ-ẓillī* in the sense of "tangent theorem" goes back to al-Bīrūnī. He presented it systematically on the basis of the beginnings made by Abu l-Wafāʾ.[83] Here we should also point out that al-Bīrūnī was probably the first to apply the rules of spherical trigonometry, formulated by his predecessors as tools of astronomy, to the advantage of mathematical geography. Due to the results which he achieved while determining longitudinal differences between Baghdad and Ghazna, there began a new period of mathematical documentation of the surface of the globe.[84]

Recently a book from the western part of the Islamic world has also come to light, the *Kitāb Mağhūlāt qusī al-kura*, written by Abū ʿAbdallāh Muḥammad Ibn Muʾāḏ[85] (still alive in 471/1079), a younger contemporary of al-Bīrūnī's.[86] The book reveals the knowledge of an equivalence of the formula $\cos \alpha = \cos a \cdot \cos \beta$ for a spherical triangle with a right angle A.[87] Until then this cosine theorem, known in a slightly different form and from Regiomontanus (1436-1476), was associated with the Latin translation of the work by Ǧābir b. Aṭaḥ (6th/12th c.).[88] According to Tropfke,[89] Regiomontanus followed Ǧābir's derivations almost literally in the fourth book of his *De triangulis omnimodis*.

We are indebted to Naṣīraddīn aṭ-Ṭūsī (d. 672/1274) for the fundamental work of Arabic-Islamic geometry. It is entitled *Kitāb aš-Šakl al-qaṭṭāʿ*. For the historiography of mathematics it proved fortuitous that this book was translated into French (see above, p. 133) in 1891 by Alexandre Pacha Carathéodory, the former foreign minister of the Ottoman Empire and that it therefore could be adequately evaluated by A. von Braunmühl, the great historian of trigonometry, [**136**] who even wrote a special study to compare it with the book by Regiomontanus (see above, p. 135). In this study he wanted to assess the question of wherein Regiomontanus's "own creative activity" lay, and he wanted to examine the validity of the opinion according to which Regiomontanus should be given the credit for having transformed trigonometry in the Occident into an independent discipline.[90] Braunmühl found that in the third chapter of his book Naṣīraddīn gave "a complete trigonometry of the plane triangle." Naṣīraddīn established the necessity for such a theory with the following statement: "In both astronomy and in the study of figures, it is of great advantage to know the methods whereby we can establish the sides and the angles of a rectangular rectilinear triangle one from another."[91] Braunmühl continues: "It follows from these words alone that he wants trigonometry to be considered not only as a mere tool of astronomical calculations, but also as an important discipline for geometrical studies. Yet in doing so Nassîr Eddîn does not only discuss the instances occurring with a rectangular triangle, by first making use of the chord method of the Greeks, but also deals with all instances of the oblique-angled triangle and,

[81] P. Luckey, op. cit., p. 420 (reprint p. 152).
[82] v. F. Sezgin, op. cit., vol. 6, pp. 266-267.
[83] *Kitāb Maqālīd ʿilm al-haiʾa*, op. cit., p. 131.
[84] v. F. Sezgin, op. cit., vol. 10, pp. 159-161, 167-168.
[85] v. ibid, vol. 5, p. 109.
[86] M. V. Villuendas, *La trigonometría europea en el siglo XI. Estudio de la obra de Ibn Muʾāḏ, El Kitāb maŷhūlāt*, Barcelona 1979 (Edition, facsimile, Spanish translation and commentary).
[87] v. ibid, introduction p. XXXV.
[88] v. A. von Braunmühl, *Nassîr Eddîn Tûsi und Regiomontan*, in: Nova Acta. Abhandlungen der Kaiserlich-Leopoldinisch-Carolinischen Deutschen Akademie der Naturforscher (Halle) 71/1897,2/31-69, esp. pp. 63-64 (reprint in: Islamic Mathematics and Astronomy, vol. 50, Frankfurt 1998, pp. 213-251, esp. pp. 245-246); idem, Vorlesungen, op. cit., vol. 1, pp. 81-82; J. Tropfke, *Geschichte der Elementar-Mathematik*, op. cit., vol. 5, pp. 131-133; P. Luckey, op. cit., p. 422 (reprint p. 154).
[89] J. Tropfke, op. cit., vol. 5, p. 137.
[90] A. von Baummühl, *Nassîr Eddîn Tûsi und Regiomontan*, op. cit., p. 33 (reprint p. 215).
[91] *Naṣīraddīn, aš-Šakl al-qaṭṭāʿ*, op. cit., Arabic p. 51, translation p. 67; v. Braunmühl, *Nassîr Eddîn Tûsi und Regiomontan*, op. cit., p. 37 (reprint p. 219).

following the 'modern method', propounds as a 'fundamental theorem' the sine theorem for which he gives two proofs."

"The first of those coincides totally with the one Regiomontanus gave in the 2nd book of his work and which was, until now, acknowledged as being his undisputed property."[92] Braunmühl regards it as quite possible that Regiomontanus used books by al-Farġānī, al-Battānī, az-Zarqālī und Ǧābir b. Aflaḥ as well as the *Libros del saber de astronomía*. However, as far as the proof of the sine theorem for the oblique-angled triangle is concerned, he says that it offered him "nothing really surprising in its conformity with that of Nassîr Eddîn, since the train of thought on which it is based was in fact the one that would be the most obvious to both of them."[93] However, Braunmühl goes on to establish that the solution of the problem of calculating the angles of an oblique-angled spherical triangle from the three sides, as stated by Regiomontanus, is likewise identical with that in Naṣīraddīn's book. In this connection Braunmühl also goes on to mention the problem of determining the three sides of the triangle from the angles, and he is the first to notice that Naṣīraddīn's solution of applying the supplementary or polar triangle is quite similar to the solution which is now named after Willebrord Snellius (1580-1626).[94] In von Braunmühl's laudable study, I cannot however endorse the view that the appearance of identical solutions of several important problems in the works of Naṣīraddīn and Regiomontanus does not lessen the latter's merits because "a connection between the writings of the two men did not exist."[95] When he was writing von Braunmühl probably inevitably came to such a conclusion since he could not imagine that Regiomontanus could know Naṣīraddīn's book without a European translation. In fact, even today no such translation is known, but other communication routes are known whereby the special achievements of the Arabic-Islamic world in later centuries reached Europe through personal contacts or via translations made for personal use. In the case of Naṣīraddīn aṭ-Ṭūsī's book, my view is that the content of this work, widely known in the Islamic world, may have been transmitted to him through Cardinal Bessarion, the former Patriarch of Constantinople, who met Regiomontanus and Georg Peurbach in Vienna.[96] If the conscientiousness with which Naṣīraddīn cites his sources is not observed by Regiomontanus, then—in the words of von Braunmühl—this should "not be judged too harshly because that was, at his time, almost always the custom."[97]

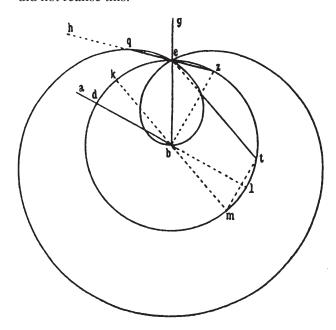
[92] v. Braunmühl, *Nassîr Eddîn Tûsi und Regiomontan*, op. cit., p. 37 (reprint p. 219).
[93] ibid, p. 39 (reprint p. 221).
[94] ibid, pp. 50-51 (reprint pp. 232-233).
[95] ibid, pp. 51-52 (reprint pp. 233-234).

[**137**] The Use of Geometrical Instruments

It can well be imagined that knowledge of the geometrical instruments used in the pre-Islamic cultures began to reach the Arabic-Islamic countries soon after an elementary knowledge of geometry had found its way into the Islamic world. It is of considerable significance for the history of mathematics that as early as approximately the middle of the 3rd/9th century Muḥammad, Aḥmad and al-Ḥasan, the three sons of Mūsā b. Šākir, were able to suggest a solution for the trisection of the angle by means of the construction of a curve. In 1923, Karl Kohl[98] investigated the question of the historical importance of the construction of the three brothers with the help of the Latin translation of their treatise on taking measurements of plane and spherical figures[99] (*Kitāb Maʿrifat misāḥat al-aškāl al-basīṭa wa-l-kurīya*). He translated the relevant part of their treatise in extracts:[100] "We can, furthermore, prove that a means has been found whereby we divide any given angle into three equal parts."

The Banū Mūsā first prove the procedure with the acute angle (see fig.), then with the obtuse angle:

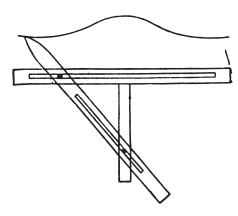
"It is also known that when the angle which we want to divide into three equal parts is larger than a right angle, we divide this one into two halves and further divide one of the two halves into three equal parts as above; it is clear that in this way we know the third part of the angle which is larger than a right angle, and that is what we wanted to show."

[96] v. F. Sezgin, op. cit., vol. 6, pp. 57-58.
[97] A. von Braunmühl, *Nassîr Eddîn Tûsi und Regiomontan*, op. cit., pp. 58-59 (reprint pp. 240-241).
[98] *Zur Geschichte der Dreiteilung des Winkels*, in: Sitzungsberichte der Physikalisch-medizinischen Sozietät (Erlangen) 54-55/1922-23/180-189 (reprint in: Islamic Mathematics and Astronomy, vol. 76, Frankfurt 1998, pp. 151-160, and in Historiography and Classification of Science in Islam, vol. 42, pp. 200-209).
[99] v. F. Sezgin, op. cit., vol. 5, pp. 251-252.
[100] *Zur Geschichte der Dreiteilung des Winkels*, op. cit., pp. 182-183 (reprint, op. cit., pp. 153-154).

On this, Kohl[101] remarks: “Because of the lucidity of the presentation it is not necessary to add special explanations to the construction. What needs to be emphasised is this: while in the constructions of their predecessors the trisection was achieved more or less by trial and error, the Benû Mûsâ here make use of motion as a systematic means of construction, long before it came to be used in the Occident.”

Kohl continues: “The curve which occurs here is, as was already mentioned, identical with Pascal’s limaçon. However, the Benû Mûsâ did not become aware of the significance of their construction. This credit goes to Stephan Pascal, viz. of having realised that with one single Pascal’s limaçon, once it had been drawn and was available, in contrast to the conchoid of Nicomedes (ca. 70 B.C.), any given angle can be divided into three equal parts. However, it becomes clear from their statements about the trisection of the obtuse angle that the Benû Mûsâ did not realise this.”

In 1874 Maximilian Curtze[102] pointed out that Copernicus, at the end of the fourth book of the copy of Euclid’s *Elements* in the 1482 edition, which was in his possession, made a remark that gives the (wrong) impression that he had *De conchoidibus* by Nicomedes at hand in connection with the trisection of the angle. In view of [**138**] the fact that the book by Nicomedes has not survived (and did not reach the Arabs either), Curtze made the correct assumption that Copernicus’s source was probably the Latin translation of the book by the Banū Mūsā which we mentioned above. Their solution by means of Pascal’s limaçon went, according to Curtze, back to Greek sources, probably to the *Kitāb al-Maʾḫūḏāt*, the *Lemmata* of (pseudo-) Archimedes. K. Kohl[103] established that the Banū Mūsā do not mention Nicomedes and that, moreover, their solution of the problem is neither identical with that of Nicomedes nor quite identical with that of the *Lemmata*.

An instrument which is known as conchoidal compasses and associated with the name of Nicomedes reached the Arab mathematicians.[104] The mathematician Abū Ǧaʿfar Muḥammad b. al-Ḥusain al-Ḫāzin (2nd half of the 4th/10th c.) reports in his “Treatise on the determination of two mean proportionals between two straight lines by means of rigid geometry” *(Risāla fī stiḫrāǧ ḫaṭṭain bain ḫaṭṭain mutawāliyain mutanāsibain min ṭarīq al-handasa aṯ-ṯābita)*[105] about this instrument and the problem that can be solved with it, but he omitted to provide a pictorial representation of the instrument. He cites the theorem and the proof of Eutocius, and adds that he had reconstructed the instrument out of wood and realised that the problem could really be solved with it. However, if it was solved with a hyperbola, this meant using rigid geometry, i.e. not using the geometry of motion.[106] The problem involves determining the “geometrical location of a point whose straight connection with a given point is intersected through a similarly given straight line in such a way that the section between the intersecting one and the location has a given length.”[107]

[101] ibid, p. 183 (reprint p. 154).

[102] *Reliquiae Copernicanae*, in: Zeitschrift für Mathematik und Physik (Leipzig) 19/1874/76-82, 432-458, esp. pp. 80-81, 448-451; 20/1875/221-248 (reprint in: Historiography and Classification of Science in Islam, vol. 42, pp. 6-69, esp. pp. 10-11, 30-33).

[103] *Zur Geschichte der Dreiteilung des Winkels*, op. cit., p. 181 (reprint, op. cit., p. 152); F. Sezgin, op. cit., vol. 5, pp. 149-150, 246-248.

[104] ibid, pp. 186-189 (reprint pp. 157-160).

[105] v. F. Sezgin, op. cit., vol. 5, p. 306.

[106] MS Paris, Bibliothèque nationale, ar. 2457, fol. 298b; cf. K. Kohl, op. cit., pp. 186-187 (reprint, op. cit., pp. 157-158).

[107] M. Cantor, *Vorlesungen über Geschichte der Mathematik*, 3rd ed., vol. 1, Leipzig 1907 (reprint New York and Stuttgart 1965), p. 351.

What is given is the straight line AB, the point C, the intersecting line CC' and the distance between B and D. What is required is the point of intersection D. As the source of this problem Abū Ǧaʿfar al-Ḫāzin mentions a book by Eutocius (6th c. A.D.),[108] in which Eutocius is said to have collected the sayings of the old geometricians.[109]

Sketch of the conchoidal compasses by M. Cantor (*Vorlesungen*, vol. 1, p. 351)

The relatively early and intensive occupation in the field of theoretical and applied geometry with curves of the third order and with the measuring of surfaces and volumes of conical figures led the mathematicians of the Arabic-Islamic world to the invention of compasses necessary for this task, where these were not known or not accessible to them from their predecessors. Al-Bīrūnī (d. 440/1048) says that as soon as it becomes necessary to place the pole of projection of astrolabe discs on a different point of the axis instead of the sphere the construction of conic sections follows (see below, p. 152).

[**139**] The great mathematician Ibrāhīm b. Sinān b. Ṯābit (d. 335/946), who occupied himself intensively with the calculation of squaring the parabola and the construction of conic sections, did not yet have a special pair of compasses for drawing conic sections. He still constructed ellipses, hyperbolas and parabolas by means of an ordinary pair of compasses and a ruler, after defining individual points (see below, p. 152). On the basis of our current knowledge we can state that Abū Sahl al-Kūhī (2nd half of the 4th/10th c.) was the first in the Arabic-Islamic world to describe the construction of a pair of compasses for drawing conic sections. The instrument which he built underwent some improvement later (see below, p. 152) by Hibatallāh b. al-Ḥusain al-Badīʿ al-Asṭurlābī (d. 534/1140).

We may close these remarks about the use of geometrical instruments with the question of the uniform opening of the pair of compasses at constant width for the solution of certain problems. For this we have at our disposal a study by W. M. Kutta from 1897 entitled *Zur Geschichte der Geometrie mit constanter Zirkelöffnung*.[110] During his research Kutta found, in the book of Abu l-Wafāʾ al-Būzağānī[111] (d. 387 or 388/998) on geometrical constructions, the first true attempt at solving geometrical problems with uniform opening of the pair of compasses at constant width.[112] After demonstrating this with the aid of some examples, Kutta states as follows: “The subsequent half a millennium of history of mathematics does not offer us any examples of attempts at such a treatment of geometrical problems. Only around the turn of the 15th century, at the time of the High Renaissance, which made accessible new visions and new horizons of thought in so many areas, including the sciences, and which reopened old ones that had been forgotten, do we encounter attempts at such solutions. Specifically they are two famous artists, who in their versatility also had a special liking for mathematics and touched upon this field, albeit only fleetingly, viz Leonardo da Vinci and Dürer.”

Summing up, we should mention here one aspect which is important both for the history of mathematics and the history of cartography and which was hitherto unknown. We are referring to the use of the open pair of compasses, which, together with the use of graduated maps, was indispensable for Arab-Islamic navigators in their voyages across the Indian Ocean.[113]

[108] v. F. Sezgin, op. cit., vol. 5, p. 188.

[109] MS Paris, Bibliothèque nationale, ar. 2457, fol. 298a.

[110] Published in: Nova Acta. Abhandlungen der Kaiserlich Leopoldinisch-Carolinischen Deutschen Akademie der Naturforscher (Halle) 71/1897,3/69-104 (reprint in: Islamic Mathematics and Astronomy, vol. 61, Frankfurt 1998, pp. 235-270).

[111] v. F. Sezgin, op. cit., vol. 5, pp. 321-325.

[112] W. M. Kutta, *Zur Geschichte der Geometrie mit constanter Zirkelöffnung*, op. cit., p. 74 (reprint, op. cit., p. 240).

[113] v. F. Sezgin, op. cit., vol. 11, pp. 267-268.

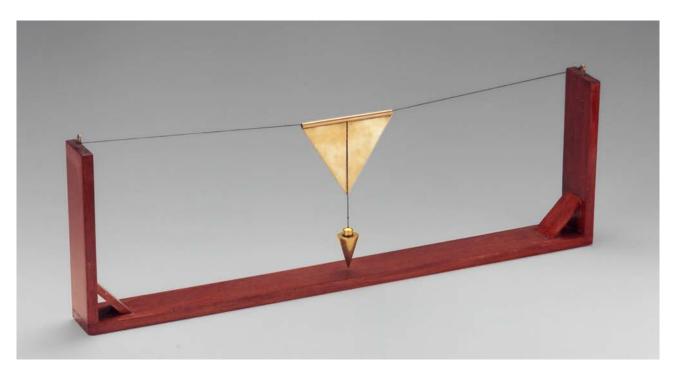
[140] Levelling Instruments

Levels with an equilateral triangle or a square as the base were apparently the most common types of this kind of levelling instrument. Known as *kūniyā*, these are mentioned by Quṭbaddīn aš-Šīrāzī (d. 710/1311) in his book *at-Tuḥfa aš-šāhīya fī ʿilm al-haiʾa*[1] in connection with the “Indian circle”.

Brass models,
height: 30 cm.
(Inventory No. D 1.04 and D 1.05).

Fig. from aš-Šīrāzī, *at-Tuḥfa*, Paris manuscript.

[1] MS Paris, Bibliothèque nationale, ar. 2516, fol. 102a.

[141] Ibn Sīnā's Levelling Instrument

Our model:
Brass gnomon with textured colour.
Brass basin, gilded.
Height: 28 cm.
(Inventory No. D 1.27)

While describing an instrument for observation which serves to measure the altitude of stars with ca. 3.5 m long arms (see above, II, 26), Ibn Sīnā (d. 428/1037) also describes a levelling instrument. A round basin is filled with water until the height of the water reaches exactly to the rim of the basin. The water should be opaque or coloured.[1]
Ibn Sīnā connects this kind of levelling with the question of setting up a gnomon vertically, which he treats in a passage of his book on "The construction of a level surface and a gnomon for determining the meridian line."[2]

[1] E. Wiedemann (with Th. W. Juynboll), *Avicennas Schrift über ein von ihm ersonnenes Beobachtungsinstrument*, in: Acta orientalia (Leiden) 11/1926/81-167, esp. 110 (reprint in: *Gesammelte Schriften zur arabisch-islamischen Wissenschaftsgeschichte*, here vol. 2, p. 1146, and in: Islamic Mathematics and Astronomy, vol. 92, pp. 137-223, esp. p. 166).
[2] "The procedure is similar with the testing of the body which is to be installed, viz. the gnomon. After it has been turned on the lathe (*ǧahr*), a circular line is cut into the gnomon, approximately at the height of the rim of the basin above the bottom of the basin." "When the gnomon is placed at the bottom of the basin and aligns this circular line with the water surface in the middle of the basin, the user knows that the gnomon is standing exactly vertical to the horizon. Here it is most practical if the water close to the gnomon is opaque (*kadir*) or blackened, because the clean, blue water deceives the eye when it should judge whether the water, the surface of the water, coincides with the line marked, i.e. with the one that was turned with the lathe. (Then through the water the bottom of the vessel, the lower part of the gnomon is visible; the observer can also be distracted by reflections.) Sometimes the former does not converge with the latter and the user thinks that it converges; on the other hand sometimes the former converges with the latter and the user thinks that this is not the case. Caution must be exercised in the manner described during the determination of the meridian line by blackening the water." (E. Wiedemann, op. cit., pp. 110-111; reprint pp. 1146-1147).

[142] Levelling Scales in Andalusia

Our model (*murǧīqal*):
Brass triangle, length of the sides 10.5 cm,
plummet and threads.
The horizontal support was added
so that the instrument could be
displayed in a show case.
(Inventory No. D. 1.06)

The Andalusian scholar Abū ʿUṯmān Saʿīd b. Aḥmad Ibn Luyūn (d. 750/1349) from Almeria[1] mentions in a didactic poem "About the manner how one levels the ground and facilitates the water flow"[2] three types of levelling instruments named *murǧīqal* ("bat", Spanish *murciélago*), *mīzān* ("scales") and *qubṭāl* ("lath", Latin cubitale) in connection with *ǧafna* ("basin").

The levelling with the murǧīqal "is done in the following manner: Two sticks of the length of an ell at a distance of 10 ells are placed erect on the ground or a similar place and a string (*šarīṭ*) joins the tip of one stick with the tip of the other suspending the murǧīqal in the middle of the string. It consists of a triangle of wood, in the middle of which a line is drawn; furthermore on it there is a thread (*ḫaiṭ*), at the end of which a weight (the lead plummet) is attached. When this falls upon the middle line of the murǧīqal and on the tip of the same, which is pointed towards the ground, then the places on the ground between the two sticks have the same height. But when the thread deviates from the line the stick at which something is missing is lifted or the stick which is too high is lowered, until the weighing is correct (the weight comes to rest). Then the location is changed with one of the sticks and the weighing is carried out again, continuing with this until the process is finished."[3]

[1] v. C. Brockelmann, *Geschichte der arabischen Litteratur*, suppl. vol. 2, p. 380; Kaḥḥāla, *Muʿǧam al-muʾallifīn*, vol. 4, p. 210.

[2] Entitled *Ibdāʾ al-malāḥa wa-inhāʾ ar-raǧāḥa fī uṣūl ṣināʿat al-filāḥa*, it is preserved incompletely in Granada (v. Brockelmann, op. cit.), i.a. also H. L. Fleischer, *Über Ibn Loyón's Lehrgedicht vom spanisch-arabischen Land- und Gartenbau*, in: *Kleinere Schriften*, vol. 3, Leipzig 1888, pp. 187-198 (reprint in: Natural Sciences in Islam, vol. 23, pp. 347-358).

[3] E. Wiedemann, *Zur Technik bei den Arabern* (Beiträge zur Geschichte der Naturwissenschaften. X), in: Sitzungsberichte der Physikalisch-medizinischen Sozietät (Erlangen) 36/1906(1907)/307-357, esp. pp. 317-318 (reprint in: *Aufsätze zur arabischen Wissenschaftsgeschichte*, vol. 1, here pp. 282-283, and in: Natural Sciences in Islam, vol. 39, pp. 135-185).

[**143**] The second levelling instrument described by Ibn Luyūn is the "scales (*mīzān*) of the masons". Levelling with it "consists of stretching a complete *qubṭāl* on to the ground or on the wall of the building by fastening the two ends. Then you put the scales into the middle of the *qubṭāl* or on to the middle of the wall. They (the scales) consist of a square piece of wood on whose centre a line has been drawn. Above this line there is a thread on whose end a tension weight (*ṯaqqāla*) is suspended …"[1]

Our model (*mīzān* with *qubṭāl*):
Wooden frame with brass
inlays for weighting, base: 50 cm.
Brass plummet.
(Inventory No. D 1.07)

The third type of levelling, viz. with basin and lath, corresponds roughly to the procedure already suggested by Ibn Sīnā with his levelling instrument (see above, p. 141). The condition of the surface which is to be levelled with a basin (*ǧafna*) is tested by Ibn Luyūn with a lath (*qubṭāl*) placed on the basin.

Our model (*ǧafna* with *qubṭāl*):
Square brass tub: 12 × 12 × 33 cm.
(Inventory No. D 1.09)

[1] ibid, p. 317 (reprint p. 282); v. also E. Wiedemann (with Th. W. Juynboll), *Avicennas Schrift über ein von ihm ersonnenes Beobachtungsinstrument*, op. cit., p. 158 (reprint p. 1194).

[**144**] The three Levelling Instruments described by al-Marrākušī

Abū ʿAlī al-Ḥasan b. ʿAlī al-Marrākušī (d. ca. 660-680/1260-1280) gives a description of three levelling instruments which contains illustrations:

The first levelling instrument described by al-Marrākušī. Our model: Brass, width: 52 cm. (Inventory No. D 1.28)

I. "You take a well-prepared rod AB of copper or a rather hard wood, sufficiently thick, so that it does not bend, divide it into two equal parts at the point S and bore a round hole there with S as the centre: to the rod you attach a tongue OCQ in such a way that the plummet, going from this tip C, coincides with CS, perpendicular to AB. Then take two feet, AKHI and BNLM, of copper or wood with a triangular base and triangular surfaces of equal size. You attach the rod carefully to these feet of equal height, making sure that the angle IAO is equal to the angle NBQ. Square feet do the

Fig. from al-Marrākušī.

same job. Then you take hangings XY, like those of scales and attach them as one does with scales, so that the point z of the inner tip of the hangings is exactly opposite the point of the tongue, so that the instrument is correctly aligned; finally you suspend a lead plummet at the end Y. — Then the instrument is placed on to the surface to be tested; if the inside tip of the hanging is in the vertical direction of the end of the tongue, then the surface is horizontal."[1]

Fig. from Th. Ibel.

[1] Al-Marrākušī, *Ǧāmiʿ al-mabādiʾ wa-l-ġāyāt fī ʿilm al-mīqāt*, facsimile edition Frankfurt 1985, vol. 1, pp. 187-188; German translation Thomas Ibel, *Die Wage im Altertum und Mittelalter*, Erlangen 1908, p. 161 (reprint in: Natural Sciences in Islam, vol. 45, Frankfurt 2001, p. 165); French translation J.-J. and L. A. Sédillot, *Traité des instruments astronomiques des arabes*, vol. 1, Paris 1834 (reprint: Islamic Mathematics and Astronomy, vol. 41, Frankfurt 1998), pp. 376-377.

Fig. from al-Marrākušī

Our model of the second
levelling instrument described by al-Marrākušī:
Brass, etched scales, with plummet.
Height: 30 cm
(Inventory No. D 1.29)

[**145**] **2.** The second levelling instrument described by al-Marrākušī and illustrated by a diagram consists of an equilateral triangle whose vertically standing sides are connected in their centre, parallel to the base, by a brass or wooden ruler. At the apex of the vertical sides a plummet is attached. While levelling, the plummet must touch the centre marking of the ruler.[2]

3. The purpose of the third levelling instrument described by al-Marrākušī is to test whether a plane surface is standing exactly vertically. For this purpose, "you attach two small laths, L_1 and L_2, preferably rectangular prisms, whose corresponding sides are equal, one of them, L_1, at the upper end of the plane, the other one, L_2 somewhat lower down, so that they correspond to each other. From the upper lath you suspend a plummet which passes the lower lath. When the thread touches the lath L_2, but without resting against it, the plane is vertical, otherwise it is not."[3]

Our model of the third levelling
instrument described by al-Marrākušī:
Hardwood, with brass plummet.
Height 30 cm.
(Inventory No. D 1.30)

[2] Al-Marrākušī, op. cit., vol. 1, pp. 188-189.
[3] Al-Marrākušī, op. cit., vol. 1, p. 189; German translation E. Wiedemann, Astronomische Instrumente (*Beiträge zur Geschichte der Naturwissenschaften*. XVIII.1), in: Sitzungsberichte der physikalisch-medizinischen Sozietät (Erlangen) 41/1909/26-46, esp. p. 29 (reprint in: Aufsätze zur arabischen Wissenschaftsgeschichte, vol. 1, pp. 544 ff., here p. 547); French translation J.-J. and L. A. Sédillot, *Traité*, op. cit., pp. 377-378.

[**146**] circular

Levelling Instrument

Our model:
Copper.
Diameter: 40 cm.
(Inventory No. D 1.08)

Mu'aiyadaddīn al-ʿUrḍī, one of the founders of the Maragha observatory (1259-1270), also describes in his book on the instruments of this observatory (see above, II, 28 ff.) a levelling instrument known as *afāḏain*, which served to test the symmetry of circular surfaces:
"From clay, out of which earthenware is made, you form a circular groove (N), which lies close to the inside rim of the ring concerned (R). (Consequently, the groove is surrounded by the ring.) The inside rim (i) of the groove is higher than the outer one (a) (which touches the inside area of the ring). You fill the groove with water and sprinkle fine ash (*ušnān*) on the water. When you have filled it with enough water, it flows out over the outer, lower rim of the ring. When this is being done, there must be complete calm, so that the water is not shaken by the wind. While the water that has been sprinkled with ashes is flowing out, any unevenness on the plane surfaces of the rings becomes noticeable and is removed with a file."[1]

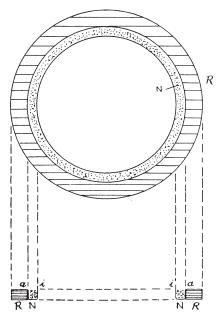



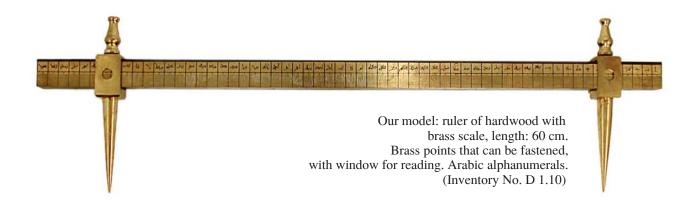
Fig. from H. Seemann.

[1] Translated from the German version by Hugo Seemann, *Die Instrumente der Sternwarte zu Marâgha nach den Mitteilungen von al-ʿUrḍî*, op. cit., pp. 49-50 (reprint pp. 52-53).

[147] Levelling Scale

Probably Ottoman, 10th -13th/16th – 19th c.
from the Institute's collection.

Copper alloy, cast, 2 parts:
plummet and spool. Height 9 cm.
(Inventory No. D 1.31)

See also: Önder Küçükerman, *Maden Döküm Sanatı*, Istanbul 1994, pp. 134 and 181 (Anatolia, 13th/19th c.).

Long Compasses

European, ca. 1850; from the Institute's collection.

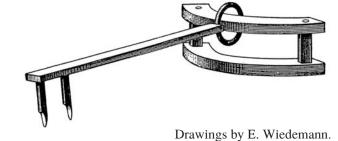
Brass, turned, 2 parts, to be joined with screw thread, length 55 and 57 cm. Two brass riders which can move on it. Inserts: two thorns and drawing-pen of steel, brass pencil lead holder. Wooden case with indents and velvet lining.
(Inventory No. D 1.22)

Our model: ruler of hardwood with brass scale, length: 60 cm.
Brass points that can be fastened, with window for reading. Arabic alphanumerals.
(Inventory No. D 1.10)

[**148**] Long Compasses
for Drawing Large Circles

Our model reproduces a specimen that can be seen among the instruments of the Ottoman astronomers in the well-known miniatures of the late 10th/16th century (see above, II, 35), where the working methods of these scholars are depicted.

Detail from *Šamāʾilnāma*, MS Istanbul, University Library, T.Y. 1404, fol. 57a.

Miniature from *Ālāt ar-raṣadīya li-zīǧ-i šahinšāhīya*. MS Istanbul, Saray, Hazine 452, fol. 16b.

[149] Compasses for Drawing Large Semicircles and Segments of Circles

Our model: circle segments which can be screwed on. Length of the drawing needle: 30 cm. (Inventory No. D 1.11)

In his treatise "On the compasses of the large circles" (*Risāla fī Barkār ad-dawā'ir al-'iẓām*), which is preserved in three manuscripts,[1] al-Ḥasan b. al-Ḥasan Ibn al-Haiṯam (d. ca. 432/1041) describes this instrument, which he probably developed. E. Wiedemann was the first to study it and make it known.[2]

Drawings by E. Wiedemann.

Compared with the circles to be drawn, the pair of compasses is small and handy, the distance between the periphery and the centre of the circle remaining constant. The instrument is equipped with several segments of circles with different radii.

[1] v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 5, p. 370.
[2] *Zur Geschichte der Brennspiegel*, in: Annalen der Physik (Leipzig) 39/1890/110-130, esp. pp. 119-120 (reprint: Gesammelte Schriften zur arabisch-islamischen Wissenschaftsgeschichte, vol. 1, pp. 59-79, esp. pp. 68-69, and in: Natural Sciences in Islam, vol. 33, pp. 116-136, esp. pp. 125-126); idem, *Über geometrische Instrumente bei den muslimischen Völkern*, in: Zeitschrift für Vermessungswesen (Stuttgart) 1910, pp. 585-592, 617-625, esp. pp. 585-592 (reprint: *Gesammelte Schriften*, vol. 1, pp. 417-433, esp. pp. 417-424, and in: Mathematics and Astronomy in Islam, vol. 57, 1998, pp. 329-345, esp. pp. 329-336).

[150] Instrument for Establishing the Centre of any Three Points and for Determining Angles on a Globe

Our model:
Brass, engraved.
length of the ruler: 70 cm,
rotating alidade, length: 36 cm.
(Inventory No. D 1.12)

It was once again E. Wiedemann[1] who drew attention to the construction and use of this instrument from the second chapter of the sixth category of the *Ǧāmiʿ* by Ibn ar-Razzāz al-Ǧazarī.[2]
The instrument consists of a protractor in a semicircular shape, one longer ruler with a scale and a shorter ruler without a scale. The latter rotates around the centre of the longer scale and around the centre of the protractor. The brass used is so thin that it is elastic and can lie flush on the surface of the globe.

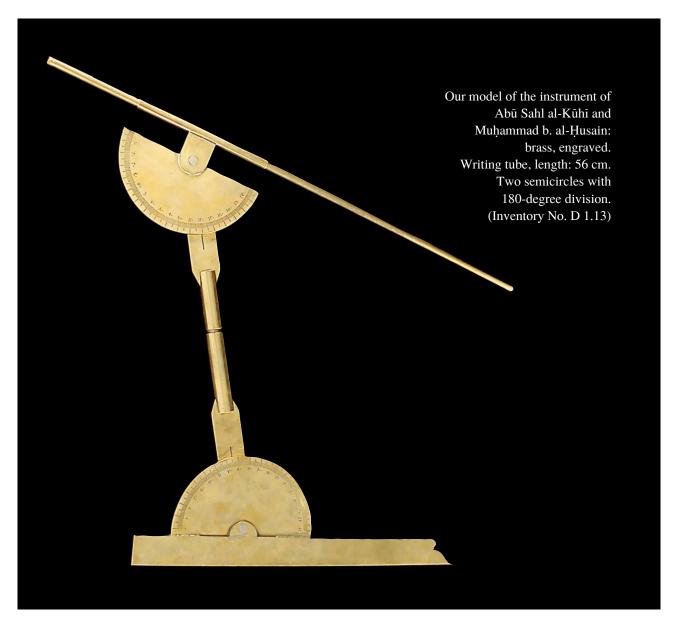



Fig. from al-Ǧazarī, *Ǧāmiʿ*, facsimile, Franckfurt, 2002, p. 518.

[1] *Über geometrische Instrumente bei den muslimischen Völkern*. 2. *Über eine Art von Transporteuren nach al Gazarî*, in: Zeitschrift für Vermessungswesen (Stuttgart) 1910, pp. 617-620 (reprint: *Gesammelte Schriften*, vol. 1, pp. 425-428, and in: Islamic Mathematics and Astronomy, vol. 57, pp. 337-340), v. also D. Hill, *The Book of Knowledge of Ingenious Mechanical Devices*, Dordrecht 1974, pp. 196-198.
[2] *al-Ǧāmiʿ bain al-ʿamal wa-l-ʿilm an-nāfiʿ fī ṣināʿat al-ḥiyal*, facsimile ed. Frankfurt 2002, pp. 514-519.

Our model of the instrument of Abū Sahl al-Kūhī and Muḥammad b. al-Ḥusain: brass, engraved. Writing tube, length: 56 cm. Two semicircles with 180-degree division. (Inventory No. D 1.13)

[151] Compasses for Drawing Conic Sections

The question of representing of conic sections in drawings was a pressing matter in the Arabic-Islamic world from since the 9th century A.D. Even then geometers and astronomers were confronted with this question, especially with regard to the construction of conic sections in the building trade and in manufacturing astrolabes. In this connection, it is still unknown what type of instruments Arabic-Islamic scholars were able to inherit from their predecessors of Late Antiquity. The mathematician Eutocius of Ascalon (2nd half of the 6th c. A.D.[1]) reports in his commentary on Archimedes' book on sphere and cylinder that Isidor of Miletus (who, together with Anthemius of Tralles, built the Hagia Sophia[2]) [**152**] had invented a pair of compasses for drawing parabolas.[3] On this

[1] v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 5, p. 188.
[2] v. ibid, p. 18.
[3] *Commentarii in libros Archimedis De sphaera et cylindro* …., in: Archimedes opera omnia, ed. J. L. Heiberg, 2nd ed., vol. 3, Leipzig 1915, pp. 84 ff.; E. Wiedemann, *Über die Konstruktion der Ellipse*, in: Zeitschrift für mathematischen und naturwissenschaftlichen Unterricht 50/1919/177-181, esp. p. 177 (reprint:

quotation from Eutocius, E. Wiedemann remarks that it seems that "there were not many such mechanical devices available otherwise, since Eutocius in his commentary to a passage in the conic sections of Apollonius I, 20-21 (edition of J. L. Heiberg p. 230ff, 233 ff.) says that, because of a lack of instruments, the mechanics construct conic sections by means of points, which are then joined up by a ruler."[4]

In his *Istīʿāb al-wuǧūh al-mumkina fī ṣanʿat al-asṭurlāb*, Abu r-Raiḥān al-Bīrūnī (d. 440/1048[5]) points out, in connection with the projection of circles on the sphere, that one is "led to the construction of conic sections as soon as the pole of projection is placed not on the pole of the sphere but at any other point of the axis."[6]

The oldest extant description of compasses for drawing conic sections comes from the mathematician and astronomer Abū Sahl al-Kūhī, who was active in the second half of the 4th/10th century in Baghdad.[7] His treatise was studied in 1874, edited and translated into French.[8] According to his own statement, Abū Sahl al-Kūhī knew of no prototype for his "perfect compasses" (*barkār tāmm*). He says: "If this instrument existed earlier with the ancients, if it was known and named and if its name and the names of its components were different from those known to us, then I may be forgiven, because neither the instrument nor an allusion to it has come down to us. However, it is possible that the instrument existed, as did also the proof that one can draw lines with it, as we mentioned, but its use in the way in which we will practise it, in the second chapter of this book did not exist."[9]

In any case, I know of no reference to date from which traces of knowledge of the instrument among Arab-Islamic mathematicians before Abū Sahl al-Kūhī could be inferred. His predecessor Ibrāhīm b. Sinān b. Ṯābit b. Qurra (d. 335/946), who occupies a prominent place in the history of the calculation of the quadrature of the parabola and who also wrote a treatise on the construction of conic sections, does not know the special compasses for drawing conic sections. He constructs ellipsis, hyperbola and parabola as before after determining individual points with the help of a simple pair of compasses and a ruler.[10]

The compasses for drawing conic sections probably underwent some improvement in the description of Hibatallāh b. al-Ḥusain al-Badīʿ al-Asṭurlābī (d. 534/1140). He called his instrument "complete perfect compasses" (*barkār kāmil tāmm*).[11]

On the basis of the reference by al-Bīrūnī, a mathematician by the name of Muḥammad b. al-Ḥusain b. Muḥammad b. al-Ḥusain (active in the last quarter of the 6th/12th c.)[12] studied Abū Sahl al-Kūhī's work and wrote a treatise on the instrument, dedicating it to Sultan Saladin (Yūsuf b. Aiyūb, [**153**] ruled 588/1193).[13] The diagram on the right is from this work.

"On the base plate a hinge is attached on the top by means of which a rod projecting upwards can be bent to the horizontal level. Around the axis of this rod a second one can be turned in the extension of the first. On the top of it a second hinge is affixed which carries a tube at the top that serves as the guide for a drawing pencil." When the rod in the extension turns, the drawing pencil describes a cone "which is intersected by the plane of the drawing that goes through the base plate."[14]

Gesammelte Schriften, vol. 2, pp. 914-918, esp. p. 914, and in: Islamic Mathematics and Astronomy, vol. 34, pp. 149-153); P. Tannery, *Eutocius et ses contemporains*, in: Mémoires scientifiques, vol. 2, Paris 1912, pp. 118-136, esp. p. 119.

4 E. Wiedemann, *Über die Konstruktion der Ellipse*, op. cit., pp. 177-178 (reprint pp. 914-915).

[5] v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 5, pp. 375 ff., vol. 6, pp. 261 ff.

[6] E. Wiedemann, *Über die Konstruktion der Ellipse*, op. cit., p. 179 (reprint p. 916).

[7] v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 5, pp. 314-321, vol. 6, pp. 218-219.

[8] *Trois traités arabes sur le compas parfait*, publiés et traduits par François Woepcke, in: Notices et extraits des manuscrits de la Bibliothèque impériale (Paris) 22/1874/1-175 (reprint in: F. Woepcke, *Études sur les mathématiques arabo-islamiques*. Nachdruck von Schriften aus den Jahren 1842-1874, Frankfurt 1986, vol. 2, pp. 560-734 and in: Islamic Mathematics and Astronomy, vol. 66, Frankfurt 1998, pp. 33-209).

[9] French translation by Fr. Woepcke, op. cit., p. 68, Arabic text ibid. p. 145 (reprint in: Études ..., pp. 627-628, 704, and in: Islamic Mathematics and Astronomy, vol. 66, pp. 102-103, 179).

[10] v. F. Sezgin, op. cit., vol. 5, pp. 292-294.

[11] His treatise devoted to this subject is preserved in a single manuscript (Istanbul, University Library, A. Y. 314, fol. 119b-122b); facs. ed. Frankfurt: Institute for the History of Arabic-Islamic Science 2001.

[12] v. C. Brockelmann, *Geschichte der Arabischen Litteratur*, vol. 1, p. 471; H. Suter, *Die Mathematiker und Astronomen der Araber und ihre Werke*, op. cit., p. 139.

[13] v. Fr. Woepcke, *Trois traités arabes*, op. cit., pp. 15-67, 116-144 (reprint, op. cit., pp. 49-101, 150-178).

[14] E. Wiedemann, *Über geometrische Instrumente bei den muslimischen Völkern*. 3. *Über Zirkel zum Zeichnen von Kegelschnitten*, in: Zeitschrift für Vermessungswesen 1910, p. 621 (reprint in: *Gesammelte Schriften*, vol. 1, p. 429, and in: Islamic Mathematics and Astronomy, vol. 57, p. 341).

This instrument, which was fairly widespread in the Arabic-Islamic world, or its description or both must have reached Europe at some time or other, perhaps more than once. There it became quite a fashion among scholars and artists throughout the entire 10th/16th century. Paul L. Rose[15] has established the connection between some models that bear the names of Leonardo da Vinci, Albrecht Dürer, Michelangelo, Francesco Barozzi (1537-1604) and others and their Arabic prototypes. Here we have restricted ourselves to the reconstruction of Barozzi's design.

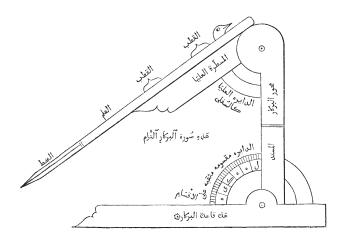
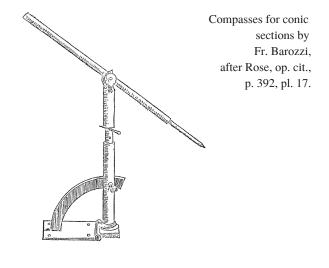



Fig. after Fr. Woepcke, *Trois traités arabes*, op. cit.

Our model:
Max. length
of the arm:71 cm,
height: 36 cm.
Brass, steel point.
(Inventory No. D 1.01)

Compasses for conic sections by Fr. Barozzi, after Rose, op. cit., p. 392, pl. 17.

[15] *Renaissance Italian Methods of drawing the Ellipse and related Curves*, in: Physis (Florence) 12/1970/371-404, esp. pp. 375 f., 392.

[154] The Compasses of Nicomedes (ca. 2nd. c. B.C.)

in the Arab-Islamic tradition

Our model, constructed on the basis of the sketches by M. Cantor and K. Kohl: wood with brass guide rails. Length of the pointer: 44 cm. (Inventory No. D 1.14)

When, in the second half of the 4th/10th century, the two procedures of geometrical proof, viz. "movable" geometry (*al-handasa al-mutaḥarrika*) and "rigid" geometry (*al-handasa aṯ-ṯābita*), had found their clear definition among the mathematicians, the mathematician Abū Ǧaʿfar Muḥammad b. al-Ḥusain al-Ḫāzin[1] introduced "the Nicomedian solution for finding the two mean geometric proportionals to two given distances,[2] calling this solution the 'method of the instrument'. Moreover, he also wanted to give a solution according to the geometrical method where he used a hyperbola."[3]

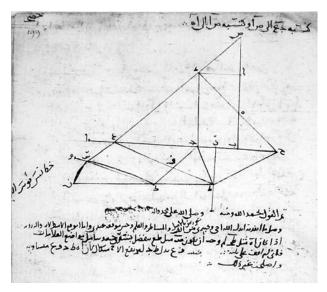
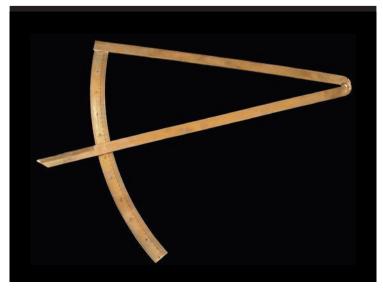



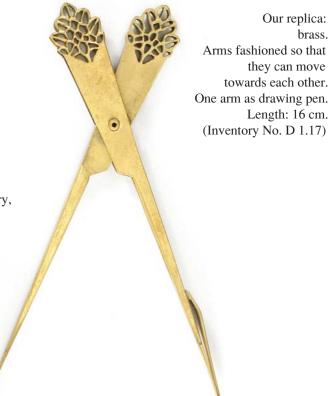
Fig.: Abū Ǧaʿfar al-Ḫāzin's depiction of the solution of the problem by means of a hyperbolic section. From MS Paris 2457/47, fol. 199.

[1] v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 5, pp. 298, 305-307, vol. 6, pp. 189-190.
[2] This "is the geometrical place of a point whose straight connection to a given point is intersected by a likewise given straight line in such a way that the distance between the intersecting line and the place has a given length" (M. Cantor, *Vorlesungen über Geschichte der Mathematik*, vol. 1, Leipzig 1907, p. 350).
[3] K. Kohl, *Zur Geschichte der Dreiteilung des Winkels*, in: Sitzungsberichte der Physikalisch-medizinischen Sozietät (Erlangen) 54-55/1922-23/180-189, esp. p. 186 (reprint in: Islamic Mathematics and Astronomy, vol. 76, Frankfurt 1988, pp. 151-160, esp. p. 157).

The same instrument of brass. Length of the pointer: 15 cm. (Inventory No. D 1.15)

[**155**] When Abū Ǧaʿfar al-Ḫāzin calls the solution of Nicomedes (probably 2nd c. B.C.[1]) the "method of the instrument", he adds that he constructed the instrument and with it tried to find the line sought.[2] Nicomedes' instrument "consisted of three rulers joined to each other. Two of them were joined firmly to each other at right angles, and while one of them was perforated by a slit almost in its entire length, the other one carried a small round peg. The perforated ruler represented the firm straight line, the peg on the other one the pole of the conchoid. Towards the pointed end the third ruler had a small peg similar to the pole and, somewhat further away from it a slit similar to that on the firm straight line; the distance of the peg from the tip represented the constant interval."[3]

[1] v. F. Sezgin, op. cit., vol. 5, pp. 149-151.
[2] K. Kohl, op. cit., p. 187 (reprint p. 158).
[3] M. Cantor, op. cit., vol. 1, p. 351.

[156] Protractor

This type of protractor is to be found among the tools of Ottoman astronomers shown in a miniature from the 10th/16th century (see above, p. 148).
The instrument permits angles to be drawn which are correct to a degree and also the measuring of given angles.

Our model:
Brass, engraved.
Length of the movable pointer: 62 cm, with a hollow for the scale (0°-50°).
(Inventory No. D 1.16)

Detail from *Šamā'ilnāma*, MS Istanbul, University Library, T. Y. 1404, fol. 57a..

A Pair of Compasses

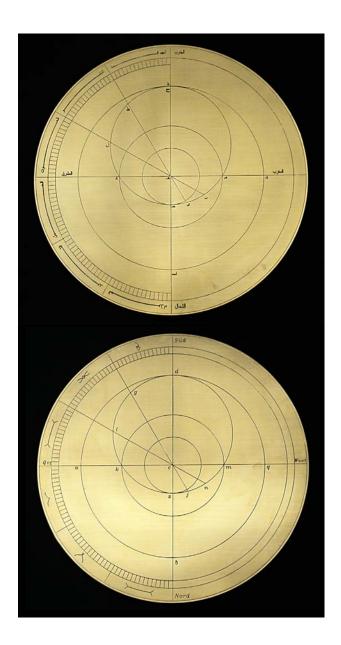
The model shows a replica of a specimen which is in the Museum of Islamic Art, Cairo.

Detail from *Šamā'ilnāma*, MS Istanbul, University Library, T. Y. 1404, fol. 57a.

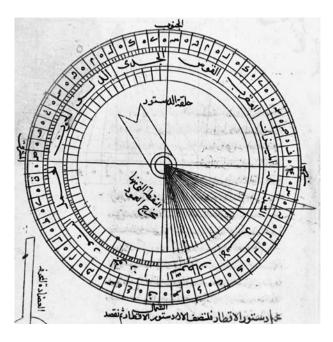
Our replica: brass.
Arms fashioned so that they can move towards each other.
One arm as drawing pen.
Length: 16 cm.
(Inventory No. D 1.17)

[157] Devices for Dividing Circles and Straight Lines

In his book entitled "Comprehensive treatment of the possible methods for producting astrolabes" (*Istīʿāb al-wuǧūh al-mumkina fī ṣanʿat al-asṭurlāb*), al-Bīrūnī gives us information on interesting details about the tools for the production of astrolabes. Among these is a *dastūr ad-dawāʾir* (device for circles), "in order to divide circles in a special way, or to transfer given arcs on them." The second instrument is called *dastūr al-aqṭār* or *dastūr al-muqanṭarāt*. It is a stencil "to divide distances of different length in the manner shown according to one and the same scale". Furthermore, a double ruler (*masṭar muṯannā*) that can be folded is described, and a pair of compasses with bent points is mentioned.[1]

❖ ❖ ❖

1. Device for Dividing Circles

Our models: brass, etched. Ø: 30.4 cm.
(Inventory No. D 1.32 and 1.33)

Al-Bīrūnī describes the characteristics of this instrument as follows: "It consists of a brass ring whose diameter is equal to the largest diameter of the plate of the astrolabe. The division of the rim of the astrolabe is done by using this *dastūr*. […] On the turning lathe (*ǧahr*) it is made level and as smooth as possible. The whole construction or application of the astrolabe depends on the *dastūr*. Its surface is divided into four parts and each part again into 90, giving 360 parts."

"However, this can only be done when the ring has been fixed on a plank and a solidifying substance has been put into its centre which prevents any shifting, so that its broad surface remains level and perfect in its expanse (probably not showing any unevenness). Now [**158**] the centre of the *dastūr* can be found and the remaining constructions implemented on it. At the beginning of the individual

[1] Eilhard Wiedemann and Josef Frank, *Vorrichtungen zur Teilung von Kreisen und Geraden usw. nach Bîrûnî*, in: Zeitschrift für Instrumentenkunde (Berlin) 41/1921/225-236, esp. p. 235 (reprint in: Islamic Mathematics and Astronomy, vol. 34, Frankfurt 1998, pp. 233-244, here p. 243).

quadrants east, west, north, south, are written each of which lie opposite one another. This only serves to facilitate the further procedures. Each quadrant is divided into three parts for the signs of the zodiac, containing 30° each; while doing this diagonals are drawn on the ring which, however, are not inscribed before the division has been prepared precisely corresponding to the ascensions of the sphaera recta."[2]

Fig. from al-Bīrūnī, *Istī'āb*.

2. Device
for Dividing Diameters

"Now we describe the *dastūr* for diameters (*dastūr al-aqṭār*), then we turn to the solution of our problem proper. Take a square plate which is so firm that it does not bend. Its side be as large as the largest diameter that is used in the construction of the astrolabe. One of the sides is divided into 120 parts, it is the number which was agreed upon at the construction of the sine. Bisect the opposite side and incise a clearly visible line between the point of bisection and each mark of division of the diameter ..."

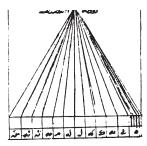



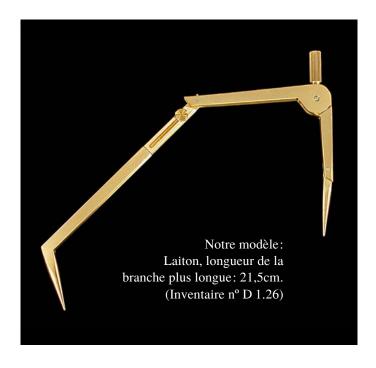
Fig. from al-Bīrūnī, *Istī'āb*.

"The use of this *dastūr* of the diameters, or as it is later also called, *dastūr* of the *muqanṭara* (parallel circles of altitude) is related to the following: from tables for the radii of the projection for the circles parallel to the Equator we can calculate in a simple way the radii of the projected *muqanṭara* for various elevations above the horizon, and while doing so the diameter of the projected Tropic of Capricorn at the northern astrolabe is put as equal to 60 or 120 parts respectively; this is at the same time the circle of the rim of the plate."[3]

Our model:
brass, etched. Measurements: 24 × 26 cm.
Scale with numbers and projection lines.
(Inventory No. D 1.19)

[2] Al-Bīrūnī, *Istī'āb al-wuǧūh al-mumkina fī ṣan'at al-asṭurlāb*, MS Istanbul, Topkapı Sarayı, Ahmet III, 3505, fol. 137b; translation E. Wiedemann and J. Frank, op. cit., p. 227 (reprint p. 235).

[3] Al-Bīrūnī, *Istī'āb al-wuǧūh al-mumkina*, op. cit., fol. 138a; translation E. Wiedemann and J. Frank, op. cit., p. 229 (reprint p. 237).

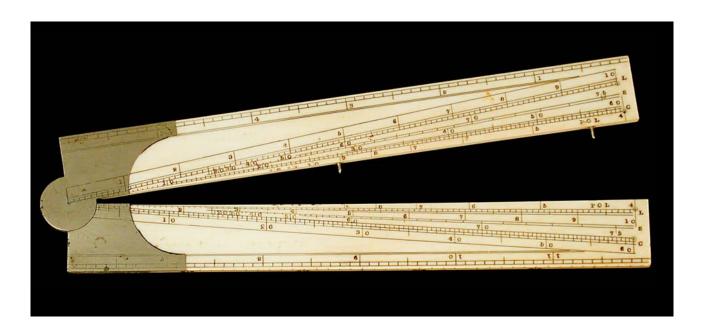
[159] 3. Foldable Double Ruler

Our model:
brass, etched. 2 arms, 26 × 1.5 cm each.
Centimetre scale with 25 parts each.
Two hinges.
(Inventory No. D 1.34)

In order to ensure that the straight lines drawn on both sides of the discs of an astrolabe were exactly opposite to each other, use was made of a foldable ruler (*masṭar muṯannā*, pl. *masāṭir muṯannāt*). These were "two similar flat rulers which could be put on top of each other in such a way that their surfaces touched each other and their edges were upon each other. They are joined by two pins at one of their ends. When an even surface is placed between them placing their edges upon the centre or upon a straight line, and joining their other ends firmly through a ring or a thread and drawing lines with them on both sides of the disc set up between them, then these are congruent and do not differ from one another. When the above-mentioned discs are divided into four parts on both sides with this double ruler, the second circle on the other side can be provided with lines exactly like those on the first side, so that they are completely congruent".[4]

[4] Al-Bīrūnī, *Istīʿāb al-wuǧūh al-mumkina*, op. cit., fol. 139b-140a; translation E. Wiedemann and J. Frank, op. cit., p. 231 (reprint p. 239).

[**160**] 4. Compasses
with Bent Points

In order to be able to draw circles on spherical surfaces even during al-Bīrūnī's lifetime (1st half of the 5th/11th c.) compasses with bent points were used.[5] What these compasses looked like has not been handed down, but we can gain an impression of their shape from our knowledge of the "perfect compasses" of the same period.

Notre modèle:
Laiton, longueur de la branche plus longue: 21,5cm.
(Inventaire nº D 1.26)

[5] v. E. Wiedemann and J. Frank, op. cit., p. 235 (reprint p. 243).

Tripod

Detail from *Šamā'ilnāma*, MS Istanbul, University Library, T. Y. 1404, fol. 57a.

Our model forms part of the tools of Ottoman astronomers as they are shown in the well-known miniature from the 10th/16th century (supra, pp. 148, 156, II, p. 35).

Hardwood. Length of the legs 110 cm.
3 legs, joined to a plate of the tripod so that they can be moved. Brass plummet fixed in the middle of the plate of the tripod. An etched brass scale on one side of each leg. (Inventory No. D 1.21)

[161] A European Slide Rule (*sector*)

Ivory ?
Length: 15 cm.
Hinge of silver.
Numbers engraved.
(Inventory No. D 1.18)

(Provenance and age unknown).

Cf. «folding rule with altitude dial», by Humfrey Cole (1574): London: The Science Museum, no. 1984–742 (in: K. Lippincott, *The Story of Time,* London, n.d., p. 121).

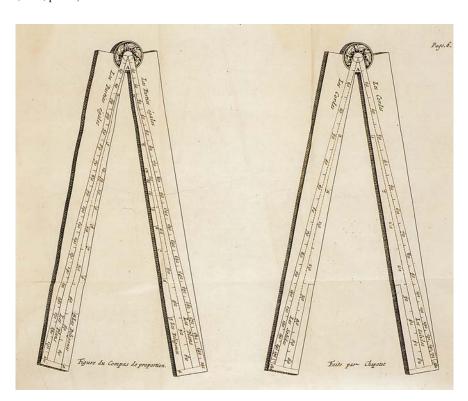



Fig.: "Escalas del sector de Gunter" in: *Instrumentos de navigación: Del Mediterráneo al Pacífico*, Barcelona n. d., p. 104

Chapter 6
Optics

[**165**] On the Theory of the Rainbow

Our model:
Hardwood, length: 74 cm.
Steel frame: 90 × 44 × 93 cm.
Plexiglass medium for the refraction of light.
Halogen lamp for demonstrations.
(Inventory No. E 2.02)

To the extent that the knowledge of the extant source material, or more precisely, of the source material investigated permits assessment, Abū ʿAlī b. Sīnā (the Avicenna of the Latin world, d. 428/1037)[1] was one of those Aristotelians who began to distance themselves not insignificantly from the great master[2] with respect to the theory of the rainbow.[3] Ibn Sīnā's views on the rainbow later exercised great influence on his successors in the Occident.[4] He states[5]: "As regards the rainbow, I have clearly recognised some factors, while I have not yet examined others sufficiently. What was usually taught about it was not adequate for me. Frequently I have noticed that the rainbow does not stand out against thick clouds. What the Peripatetics, a school to which I belong, teach about it, does not satisfy me at all. First I wish to [**166**] describe the rainbow as it appears in those areas where there are no thick clouds, in the way that I myself observe it. Then I explain why it consists only of a semicircle or less. At the same time I show why the rainbow does not

[1] v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 6, pp. 276-280, vol. 7, pp. 292-302.
[2] v. E. Wiedemann, *Theorie des Regenbogens von Ibn al Haiṯam* (= Beiträge zur Geschichte der Naturwissenschaften. 38), in: Sitzungsberichte der Physikalisch-medizinischen Sozietät (Erlangen) 46/1914 (1915)/39-56 (reprint in: *Aufsätze zur arabischen Wissenschaftsgeschichte*, vol. 2, pp. 69-86, and in: Natural Sciences in Islam, vol. 33, pp. 219-236).
[3] On the literature about the rainbow, v. G. Hellmann, *Meteorologische Optik 1000-1836*, Berlin 1902 (= Neudrucke von Schriften und Karten über Meteorologie und Erdmagnetismus. no. 14).
[4] M. Horten, *Avicennas Lehre vom Regenbogen nach seinem Werk al Schifâ. Mit Bemerkungen von E. Wiedemann*, in: Meteorologische Zeitschrift 30/1913/533-544, esp. p. 533 (reprint in: *Gesammelte Schriften*, vol. 2, pp. 733-744, esp. p. 733).
[5] *aš-Šifāʾ. aṭ-Ṭabīʿīyāt* 5: *al-Maʿādin wa-l-āṯār al-ʿulwīya*, eds. Ibrāhīm Madkūr, ʿAbdalḥalīm Muntaṣir, Saʿīd Zāyid, ʿAbdallāh Ismāʿīl, Cairo 1965, p. 50. Translation M. Horten, op. cit., p. 539 (reprint p. 739).

occur at all times of the day in summer, but in winter. About its colours I myself have no clear opinion as yet. I do not know their cause, nor am I satisfied with the theory of others, which is quite erroneous and foolish."

Ibn Sīnā's expositions about the rainbow, only a selection of which was translated by M. Horten, show a natural philosopher who observed this optical-meteorological phenomenon repeatedly and also investigated it experimentally. When he admits in the end that he considers his insights not yet reliable enough to include them in his book,[6] then this is "significant from the viewpoint of the history of civilisation that the Muslim scholar is frequently discreet with his judgments about the physical world."[7]

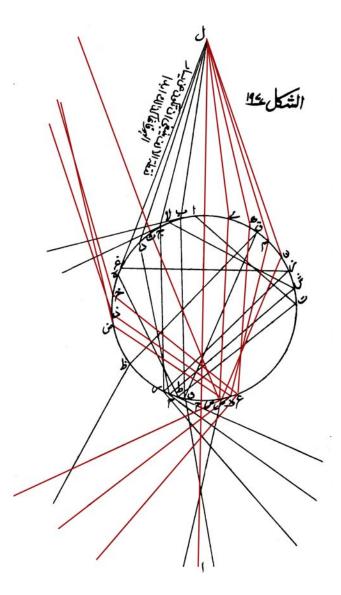
Two aspects of Ibn Sīnā's expositions are worthy of note. First, that he "locates the seat of the rainbow not in the cloud itself, but in front of it, in the fine vapour,"[8] and second, that he refutes the Peripatetic view of the rays of vision proceeding from the eye to the object, and follows instead the physicists (*ṭabīʿīyūn*), according to whose opinion the process of seeing takes place through rays of light which emanate from the object and reach the eye.[9]

Among the physicists whom Ibn Sīnā mentions, an outstanding position is occupied, no doubt, by al-Ḥasan b. al-Ḥasan Ibn al-Haiṯam (b. ca. 354/965, d. after 432/1041),[10] his contemporary and senior by about 15 years. Known in Europe as Alhazen, this eminent mathematician, astronomer and physicist, who came to the fore with a new optics arrived at by systematic experiments, developed his own meteorological-optical explanation for the phenomenon of the rainbow in his treatises on the circular burning glasses[11] and on the rainbow and the halo.[12] Although with his explanation of the origin of the rainbow through reflection on a concave spherical cloud,[13] Ibn al-Haiṯam did not understand the true state of affairs, nevertheless, he laid a solid foundation for further experiments which, after about 250 years, led to a revolutionary breakthrough.

It was Kamāladdīn Abu l-Ḥasan Muḥammad b. al-Ḥasan al-Fārisī (d. 718/1318), a versatile natural scientist, who declared the explanation of the preceding scholars about the origin of the rainbow through simple reflection of light on drops of water to be incorrect.[14] In his opinion the optical perception of the rainbow is based on the peculiar nature of the transparent spherical drops which lie close to one another. The perception results from double refraction and one or two reflections as the sunlight enters into and comes out of the individual drop. He arrived at this conclusion on the basis of systematically conducted experiments with a sphere made of glass or rock-crystal. Kamāladdīn's reasoning, [**167**] his manner of experimenting, his conclusions and their importance for the history of meteorological optics were studied repeatedly by Eilhard Wiedemann and, at his suggestion, by Joseph Würschmidt.[15]

[6] ibid, p. 55.

[7] M. Horten, *Avicennas Lehre vom Regenbogen*, op. cit., pp. 543-544 (reprint pp. 743-744).

[8] ibid, p. 543 (reprint p. 743).

[9] *aš-Šifāʾ*, op. cit., p. 41; M. Horten, op. cit., p. 533 (reprint p. 733).

[10] v. F. Sezgin, op. cit., vol. 5, pp. 358-374; vol. 6, pp. 251-261; vol. 7, p. 288.

[11] *Maqāla fi l-marāya l-muḥriqa bi-d-dāʾira*, ed. in *Maǧmūʿ ar-rasāʾil* ... Ibn al-Haiṯam, Hyderabad 1357/1938 (reprint: Islamic Mathematics and Astronomy, vol. 75); cf. Roshdi Rashed, *Géométrie et dioptrique au Xe siècle. Ibn Sahl, al-Qūhī et Ibn al-Haytham*, Paris 1993, pp. 111-132.

[12] *Maqāla fī qaus quzaḥ wa-l-hāla* in the recension of Kamāladdīn al-Fārisī in the appendix to *Kitāb Tanqīḥ al-Manāẓir li-ḏawi l-abṣār wa-l-baṣāʾir*, vol. 2, Hyderabad 1348/1929. pp. 258-279.

[13] He "showed in his treatise on the spherical concave mirror that, when rays emanate from a luminous point b which is very far away and reach through reflection in a spherical concave mirror a point a, lying on the axis, this is only the case with the reflection at a circle which is concentric to the axis. If the luminous body has a specific expanse, then a circular ring of greater or lesser width must take the place of the circle. Well, the cloud represents such a concave mirror and the circular ring corresponds to the rainbow. The colours are explained as usual as a mixture of light and shadow" (E. Wiedemann, *Theorie des Regenbogens von Ibn al Haiṯam*, op. cit., p. 40, reprint p. 70).

[14] *Tanqīḥ al-Manāẓir*, op. cit., vol. 2, pp. 283-284.

[15] E. Wiedemann, *Über die Brechung des Lichtes in Kugeln nach Ibn al Haiṯam und Kamâl al Dîn al Fârisî*, in: Sitzungsberichte der Physikalisch-medizinischen Sozietät (Erlangen) 42/1910/15-58 (reprint in: *Aufsätze zur arabischen Wissenschaftsgeschichte*, vol. 1, pp. 597-640, and in: Natural Sciences in Islam, vol. 34, pp. 213-256); idem, *Über das Sehen durch eine Kugel bei den Arabern*, in: Annalen der Physik und Chemie (Leipzig) N.F. 39/1890/565-576 (reprint in: Gesammelte Schriften, vol. 1, pp. 47-58 and in: Natural Sciences in Islam, vol. 34, pp. 195-206); idem, *Zur Optik von Kamâl al Dîn*, in: Archiv für die Geschichte der Naturwissenschaften und der Technik (Leipzig) 3/1911-12/161-177 (reprint in: *Gesammelte Schriften*, vol. 1, pp. 596-612 and in: Natural Sciences in Islam, vol. 34, pp. 263-279); Joseph Würschmidt, *Über die Brennkugel*, in: Monatshefte für den naturwissenschaftlichen Unterricht aller Schulgattungen (Leipzig and Berlin) 4/1911/98-113 (reprint in: Natural Sciences in Islam, vol. 34, pp. 280-295); idem, *Dietrich von Freiberg: Über den Regenbogen und die durch Strahlen erzeugten Eindrücke*, Münster 1914.

Kamāladdīn al-Fārisī, *Tanqīḥ*, Hyderabad vol. 2, fig. 192.

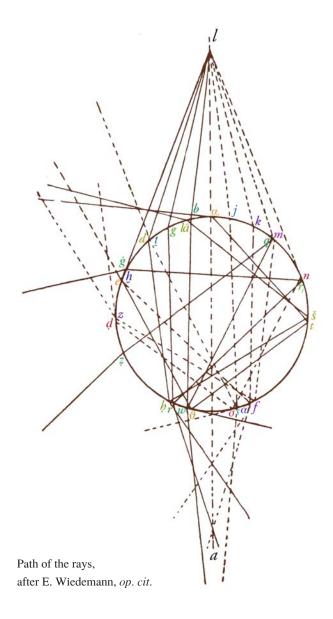
By means of the adjacent figure (with black and red lines in the manuscript) Kamāladdīn describes the procedure as follows: "Now we draw, according to our explanations, a figure that facilitates understanding. As before, we draw the circle and the burning-cone. From the mid point *l* [ل] of the eye we draw the axis *la*. Furthermore we draw a line between the axis and the border ray of the middle cone, this border ray itself, the border ray of the outer hollow space and a line between it and the inside. We draw these lines and those originating from them black on the right side [of the eye of the person conducting the experiment, which is at *l* (ل)] and red on the left side. Then, for the rays of the left side, we draw the refracted chords, the reflected ones originating from them and those reflected ones originating from these and refracted in the air; they constitute the rays which have been reflected and refracted once. For the rays of the right side, we draw the refracted chords, the reflected ones originating from them, the ones which are reflected once more and those refracted in the air. These are the twice reflected and refracted rays."

"The rays on the right of the straight continuation of the cone are *lb*, *lg*, *ld*, *le*; the rays on the left are *lj*, *lk*, *lm*, *ln*. The right ones are deflected towards the chords *bw*, *gr*, *dḥ*, *eϑ*, the left ones towards the chords *js*, *kα*, *mf*, *nσ*. All are deflected into the air so that the burning cone originates from their chords. Then the chords are reflected in the sphere itself to other points, namely the right ones to the points *q*, r_1, *š*, *t* and the left ones to the points *ṯ*, *ẖ*, *z*, *ḍ*. The rays of the two bands are refracted in the air in such a way that from their chords the refracted cone is formed with [**168**] a reflection to the side of the eye, and the positions of the rays are in it different [than before], out of those lying on the right originate those lying on the left and vice versa. Those drawn in the figure are those lying to the right of the eye."

"The chords *wq*, rr_1, *ḥš*, *ϑt*, i.e. the rays on the right after single refraction in the sphere and a first reflection from right to left are reflected a second time towards the points *ẓ*, *ġ*, *lâ*, α_1, then they are refracted into the air in such a shape that from their chords the deflected cone appears with two reflections; it lies on the side opposite the eye. Only the chords lying on the right, corresponding to the right rays are illustrated."[16]

This is followed by the description of his observations while experimenting with single refraction and reflection (*iʿtibār al-munʿaṭif bi-nʿikās*) and with double refraction and reflection (*bi-nʿikāsain*).[17] J. Würschmidt, who studied these expositions with the help of Wiedemann's translation in 1911, comments: "The theoretical expositions of this chapter are very detailed and some passages are difficult to understand, but it emerges from the whole presentation that for both cases, for single and double reflection, he clearly recognised the importance of the reverse rays. With regard to his observations, one experiment[18] particularly

[16] Kamāladdīn al-Fārisī, *Tanqīḥ al-Manāẓir*, op. cit., vol. 2, pp. 316-317; translation E. Wiedemann, *Über die Brechung des Lichtes*, op. cit., pp. 53-54 (reprint pp. 635-636, or pp. 251-252).

[17] Kamāladdīn, *Tanqīḥ al-Manāẓir*, op. cit., vol. 2, pp. 317-319; translation E. Wiedemann, *Über die Brechung des Lichtes*, op. cit., pp. 54-56 (reprint pp. 636-638, or pp. 252-254).

[18] On the experiment, v. Kamāladdīn, *Tanqīḥ al-Manāẓir*, op.

should be specially mentioned, since it is completely identical with that which Goethe and Boisserée[19] conducted 500 years later. That is to say, he finds the appearance of the two images with the (single or double) reflection; with the appropriate position of the eye at first one image is seen; when the eye is moved towards the edge of the sphere that is closest to this image, the second image appears from the edge. Both images are coloured red towards the outside (as a consequence of dispersion they display the spectral colours), then they come closer and closer and converge into one image; that is coloured yellow (the blue and violet parts of both spectra having already disappeared). Then the yellow one disappears and a red image remains, until that one also disappears."

"The Arab scholar also demonstrates in an elegant way the direct observation of the rainbow originating through single reflection. That is to say, he screens one half of the sphere with an opaque white surface, placed between the sphere and the source of light; then on this half the rainbow that is forming through the rays which [**169**] have hit the other half of the sphere becomes visible, the rainbow becoming smaller and brighter as the white surface is brought closer to the sphere."[20]

Kamāladdīn dealt exhaustively with the ratio of the angles of incidence of the rays into the sphere (and, by analogy, into the water droplet) to the angles of refraction, and prepared a table of refraction. Yet he contented himself with recording the values at intervals of 5° and added that more precise results could be achieved by proceeding one degree after the other. He did not give an explicit statement on the maximum and minimum limit of the angle of incidence for the formation of a rainbow, but it seems he assumed it was between 40° or 50° respectively.[21] The figures 41° to 42° as the lower limit and 51° or 52° as the upper limit appear clearly in René Descartes[22] (as against the modern values of 42° and 52°). With this exception, Kamāladdīn's treatment of the rainbow is superior "in the theoretical assessment" to that of Descartes.[23] One of his important findings is that "a sphere of rock crystal, which is placed opposite the sun, causes a burning on the side opposite to the sun, namely at a distance from the sphere smaller than 1/4 of its diameter."[24] Moreover, he discovered "the reflection on the front part of the lens of the eye, which was rediscovered by Evangelista Purkynje only in 1823".[25]

Finally we may briefly discuss the relationship between the treatise by Dietrich von Freiberg (Theo-

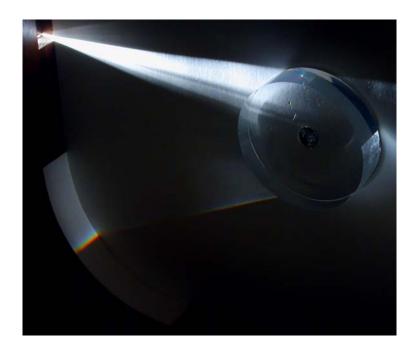
Path of the rays,
after E. Wiedemann, *op. cit*.

cit., vol. 2, pp. 318-319; translation E. Wiedemann, *Über die Brechung des Lichtes*, op. cit., p. 55 (reprint p. 637, or p. 253).

[19] For J. W. von Goethe's and Sulpiz Boisserée's observation, v. J. Würschmidt, *Über die Brennkugel*, op. cit., pp. 100-101 (reprint pp. 282-283).

[20] J. Würschmidt, *Über die Brennkugel*, op. cit., pp. 112-113 (reprint pp. 294-295).

[21] v. *Tanqīḥ al-Manāẓir*, op. cit., vol. 2, pp. 296-299; translation E. Wiedemann, *Über die Brechung des Lichtes*, op. cit., pp. 31-36 (reprint pp. 613-618, or pp. 229-234); J. Würschmidt, *Über die Brennkugel*, op. cit., pp. 102-103 (reprint pp. 284-285).

[22] v. G. Hellmann, *Meteorologische Optik*, op. cit., pp. 17-30.

[23] Matthias Schramm, *Ibn al-Haythams Stellung in der Geschichte der Wissenschaften*, in: Fikrun wa Fann (Hamburg) 6/1965/2-22, esp. p. 21; cf. J. Würschmidt, *Über die Brennkugel*, op. cit., p. 102 (reprint p. 284).

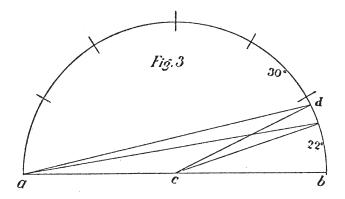
[24] J. Würschmidt, op. cit., p. 104 (reprint p. 286).

[25] M. Schramm, Ibn *al-Haythams Stellung*, op. cit., p. 21.

doricus Teutonicus), *De iride et radialibus impressionibus*, and Kamāladdīn's work. Dietrich von Freiberg was a Dominican monk about whose life little is known. The assumption may be correct that he was a contemporary of Kamāladdīn al-Fārisī and wrote his treatise in the first decade of the 14th century. Because of the entirely new explanation of the formation of the rainbow, which appears in this treatise, G. Hellmann[26] called it in 1902, "the greatest achievement of its kind of the Occident in the Middle Ages." What he meant was the formation of the rainbow as a consequence of double refraction and single or doublet reflection of light in a water drop. Thanks to the translation and the study of Kamāladdīn's text by E. Wiedemann, it became known in the first decade of the 20th century that the explanations which came as a surprise in Dietrich's treatise are to be found in exemplary form in the book of his contemporary from the Arabic-Islamic world. At the suggestion of E. Wiedemann, J. Würschmidt discussed the question of a possible connection between the two books:[27] "Kamâl al Dîn, most remarkably, avoided a number of mistakes which are to be found in Dietrich and likewise in earlier Arab scholars [**170**] and, in particular, recognised the nature of the 'reverse ray' which became so important for the theory of the rainbow later propounded by Descartes …"

"Thus we have two great contemporary works, independent of one another, which deal with the question of the formation of the rainbow, which both go back to common sources, but contain a different continuation of the impulses received from these. In both works the theoretical observations are supported by experiments; Dietrich even places the experiment higher than the philosophical reasoning of his master Aristotle, with the argument: 'The same Aristotle also taught us that we should not give up that which has been proved experimentally.' This sentence, particularly, deserves, in my opinion, to be especially emphasised; because we may consider this esteem shown to experiments a heritage adopted from the Arabs, from those Arabs who, like Kamâl al Dîn especially, displayed such a highly developed art of experimentation, which is exemplary even today."[28]

Würschmidt points to traces of influence of Arab predecessors like Ibn al-Haiṯam, Ibn Sīnā or Ibn Rušd in Dietrich's work and deduces: "From this we see that Dietrich probably derived information not only from Alhacen's optics, but also from other Arabic sources; however, in many points he went beyond that which earlier scholars had achieved, particularly by realising, independently of Kamâl al Dîn, that double refraction and single reflection of the sun's rays occur in the droplets of water, and by making this fact the basis of his theory. Although he did not thereby achieve as much as Kamâl al Dîn did with his recognition of the reverse ray, we must still appreciate and admire the execution of his basic idea to the extent that it was possible for him without the knowledge of the law of refraction. For centuries after him no one succeeded in giving an explanation that was substantially better; it was left to modern times to provide a complete solution of the problem on the basis of the theory of diffraction."[29] In Würschmidt's time, when the methods and paths of the process of the reception and assimilation of Arabic-Islamic sciences in the Occident were even less clear than they are now, this was perhaps the only possible explanation. True, even today we have not progressed much farther, but in

[26] *Meteorologische Optik*, op. cit., p. 8.
[27] *Dietrich von Freiberg*, op. cit., pp. 1-4.
[28] J. Würschmidt, *Dietrich von Freiberg*, op. cit., p. 2.
[29] ibid, p. 4.

the meantime we know enough examples of how achievements or discoveries, as well as books or also maps and scientific-technical instruments from the Arabic-Islamic world were rapidly disseminated. Kamāladdīn and Dietrich lived at a time when brisk human contacts spread out from Persia under the Ilkhans. The western path led from Tabrīz and Marāġa via Trebizond and Constantinople to Italy and eastern Europe. The mediators of innovations were often the clergy, but not infrequently also travellers or ambassadors.

We should not fail to mention one observation by Würschmidt. He finds, in particular, one figure in the finite interesting, because in this figure both Kamāladdīn and Dietrich erroneously assume that "the sun is at infinity, in fact at the same distance from the rainbow or from the mirror that replaces the rainbow here, as the eye of the observer."[30] But when we look at another of Dietrich's figures **[171]** to which Engelbert Krebs[31] drew attention, then, when explaining it, he commits "the unbelievable error of making the area of the arc: sun *a* iris apex *d* always equal to 158° instead of equal to 138°, with the consequence that he calculates the iris radius as 22° instead of 42° […]. That the numbers 158° and 22° instead of 138° and 42° are not an error in writing in the manuscripts … follows from chapter 8 of part III, where he makes the diameter of the halos equal to 22° [that is to say the radius equal to 11°] and then notices that the diameter of the halo is half as large as the diameter of the iris, which agrees with his wrong numbers, while in reality the radial proportion is iris : halo = 4 : 1. An explanation for these wrong numbers can only be given with the argument that Dietrich himself, who was only interested in the speculative proof, not in the commonly known measurement, copied the well known number 138° wrongly and on that basis made his calculations, all of which can be traced back to this number."[32]

In my opinion, Würschmidt's conclusion that Dietrich cannot have known Kamāladdīn's work because it does not contain "a number of errors" present in Dietrich's treatise cannot be upheld. The state of affairs can be explained by assuming that Dietrich did not fully understand the content of Kamāladdīn's work or did not know it directly. In this connection one of Dietrich's specific errors seems to me to be revealing. In his main figure for the representation of the five colour rays he lets them erroneously emerge parallel from the individual water droplet, while otherwise he quite correctly "lets the colours originate in the eye c through the rays of different droplets, with only one colour of each droplet striking the eye"[33] – as in Kamāladdīn. When it is taken into account that none of the contemporaries of Dietrich von Freiberg who dealt with the subject of the origin of the rainbow, such as Roger Bacon or Witelo, or, after these, Francesco Maurolico (d. 1575) down to René Descartes (d. 1650), progressed notably in this question beyond the results of Ibn al-Haiṯam, when, furthermore, the grave errors and the absence of "a mathematical understanding of the subject"[34] in Dietrich are remembered, and when one is sufficiently conversant with the methods and paths of acceptance of Arabic-Islamic sciences at that time, the conclusion emerges without any difficulty that Kamāladdīn al-Fārisī's work did indeed fall on fruitful ground only a few years after its appearance in Europe, even if only with one single person.

It is highly instructive that Otto Werner[35] in a study of 1910 on Leonardo da Vinci's physics surmised that Kamāladdīn's work must have been known in the Occident and must have been used by Leonardo. He was astonished to see "how exactly a figure in the Codex Atlanticus [of the work of Leonardo] on fol. 238r-b … agrees with that of Kamâl al Dîn al Fârisî." In his opinion, "the close connections ex-

Drawing from E. Krebs, *Meister Dietrich*, texts, p. 32.

[30] ibid, p. 3.

[31] *Meister Dietrich (Theodoricus Teutonicus de Vriberg). Sein Leben, seine Werke, seine Wissenschaft*, Münster 1906, pp. 32*-33*.

[32] ibid, p. 2.

[33] E. Krebs, *Meister Dietrich*, op. cit., p. 34*.

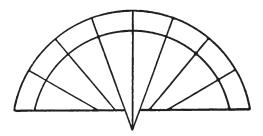
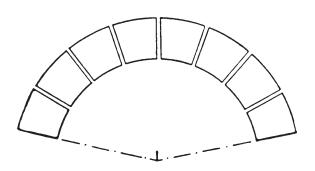
[34] M. Schramm, *Ibn al-Haythams Stellung*, op. cit., p. 21.

[35] *Zur Physik Leonardo da Vincis*, op. cit., p.111.

isting between the rainbow theorem of Theodosius Saxonicus and the one by Kamâl al Dîn al Fârisî" also argue in favour of an acquaintance in Europe with Kamāladdīn's book.

Our model serves to demonstrate the theoretical approach with which Kamāladdīn al-Fārisī develops the phenomenon of the rainbow; a single drop, abstracted to a round disc with a higher index of refraction than the medium (the glass or rock crystal used by Kamāladdīn) permits the demonstration of the paths of the rays (see above) resulting from double refraction and one or two reflections as the ray of light enters into and exits from the individual droplet, as shown in the figure from the *Tanqīḥ al-Manāẓir* (see above).

[172] Apparatus
for the Observation of the Reflection of Light

Our model:
Hardwood, stained.
Diameter of the half-cylinder: 28 cm.
7 different mirrors to be inserted in the appliance.
(Inventory No. E 2.06)

In the fourth tract (*maqāla*) of his great book of optics (*Kitāb al-Manāẓir*), Ibn al-Haiṯam (d. after 432/1041) discusses the theory of the reflection of light in great detail. After that he gives an exemplary description of his "reflection apparatus" (*ālat al-inʿikās*) and its use. The apparatus is meant to demonstrate the law of reflection, which states that the angle of incidence is the same as that of reflection. Besides, it serves to demonstrate that this law is also true for reflections in cylindrical, conical and spherical mirrors and with coloured rays of light. In the extant manuscripts of the *Kitāb al-Manāẓir* the figures are missing. This was already deplored by the commentator Kamāladdīn al-Fārisī, who mentions that in his commentary he had removed this shortcoming by adding his own figures (which are reproduced in the following).[1] For this instrument also we are obliged to Muṣṭafā Naẓīf[2] for an excellent description and the necessary figures. According to Ibn al-Haiṯam, it consists of two main components and a number of auxiliary parts. One of the basic components is a semicircular brass plate, the original shape of which corresponds to a semicircle with a diameter of ca. 10 cm. Of this only the tip remains, as is shown in the sketch.

Towards the edge on both sides 2 cm wide segments are removed. The tip of the remaining triangle corresponds to the centre of the circle that defines the brass plate.

[1] *Tanqīḥ al-Manāẓir*, op. cit., vol. 1, p. 339.
[2] *al-Ḥasan b. al-Haiṯam*, op. cit., pp. 346-363.

Figures from M. Naẓīf, op. cit., pp. 347–351.

[**173**] The second main component is a half cylinder of wood which rests firmly on a round wooden base as is shown in the cross-section of the adjacent sketch. Ibn al-Haiṯam stresses the necessity of using wood of very good quality. The outer diameter of the cylinder is 28 cm, the thickness of its wall 4 cm and its height 12 cm. Into the inside wall of the cylinder the brass plate described above is inserted, parallel to the base and at a distance of 4 cm from it. The brass plate is pushed up to the middle of the wall of wood (2 cm) into a groove so that its inner circumference is tangent to the inner wall of the cylinder. Then [or rather: before that] seven cylindrical holes of 1 cm diameter each are drilled through the wooden wall in such a way that they are tangent to the plate from above and their axes are parallel to the seven radii lying under them, which are drawn on the plate.

In the wooden base a rectangular depression has been cut out in front of the open half cylinder into which the mirrors are inserted which are needed for the observations. Seven mirrors are provided with the corresponding receptacles: a plane one, two spherical ones, two cylindrical ones and two conic ones (each of them concave and convex). They are fitted into the depression and affixed in such a way that their centre in each case comes into contact with the tip of the brass plate. While experimenting, six of the seven holes are blocked on the outside of the half-cylinder and pasted over on the inside with a piece of white paper. This is firmly pressed with a finger until the round rim can be seen and the centre of the opening can be marked with a fine pen.

For observations with this apparatus Ibn al-Haiṯam prefers a room into which the sunlight falls through a narrow hole. The device is installed in such a way that the sunlight strikes the mirror through the hole opened at that time and is reflected there. The reflected light can then be seen from the inside of the half-cylinder at the hole that was pasted over, which forms an equilateral triangle with the open hole and the tip of the brass plate. If the person conducting the experiment switches the role of the holes they will achieve the same effect. It is also possible to use a tube whose diameter is chosen in such a way that it just fits into one of the holes and whose length corresponds to the diameter of the cylinder so that it touches the centre of the mirror with its end.

[174] Instrument

For Observing Moonlight

Our model:
Wood (oak), stained and lacquered.
Observation rail with a diopter running in a groove. Length: 50 cm.
Brass joint with set screws.
Height of the stand: 100 cm.
(Inventory No. E 2.07)

In his "Treatise on the light of the moon" (*Maqāla fī Ḍau' al-qamar*[1]), Ibn al-Haiṯam (d. after 432/1041) wishes to show "that the moon behaves like a self-luminous body and therefore differs fundamentally from reflecting or transparent luminous bodies which only let the light pass through."

[1] v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 6, pp. 255-256. The treatise was published in 1357 (1939) in Hyderabad (reprint in: Islamic Mathematics and Astronomy, vol. 75, 8th text), German translation Karl Kohl, *Über das Licht des Mondes. Eine Untersuchung von Ibn al-Haitham*, in: Sitzungsberichte der Physikalisch-medizinischen Sozietät (Erlangen) 56-57/1924-25 (1926)/305-398 (reprint in: Islamic Mathematics and Astronomy, vol. 58, pp. 135-228), detailed analysis by M. Schramm, *Ibn al-Hayṯhams Weg*, op. cit., pp. 70-87, 130-189.

[**175**]"He defined the term self-luminous body as distinct from these other cases in the following way: from each of its points light goes out to each point lying opposite to it. Now he wants to prove that the moon's luminous surface satisfies this condition."[2]

To explain this characteristic of moonlight, Ibn al-Haiṯam constructs an instrument[3] which he describes in detail: "In order to examine the characteristics of moonlight, we take a ruler of convenient length, width and thickness which is exactly straight and has a flat surface. To its ends we attach (perpendicularly to the plane surface) two sight vanes of suitable length, parallel to each other, which are equally long and equally wide; their width should be the same as that of the ruler. In the middle of one of them, near the end of the ruler, we make a cavity with smooth walls, resembling a hemisphere, and drill a small round hole in its centre. From the middle of the other sight vane we draw a straight line parallel to the surface of the ruler. It is as far away from the surface of the ruler as the middle of the hole in the first vane. Its length measured on the width of the vane is chosen in such a way that, seen from the centre of the hole in the first vane, it corresponds to an angle which is not smaller than the angle under which the diameter of the moon appears to the eye. We arrange it in such a way that the rest of the length of the two vanes as well as the width of the vane which has the line, on both sides together are not smaller than the length of the line. We cut out this line until it goes through the thickness of the vane and make the edge as smooth as possible (we then have a slit in the vane). Then we take another ruler with parallel surfaces which is considerably longer but as wide as the first one. With this we join the first ruler and bring the end where the vane with the slit is exactly to the end of the second rectangular ruler. At the two joined ends an axis (a hinge) is affixed around which they turn. The other end of the second long rectangular ruler is attached to a square base, a block, so that this ruler has the shape of the instrument with the two arms."

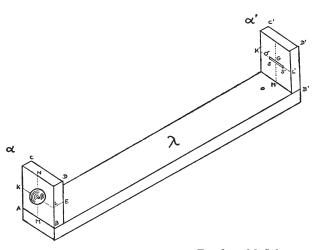



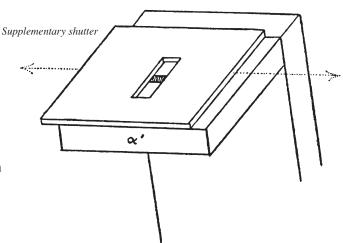
Fig. from M. Schramm, *Ibn al-Hayṯams Weg*, p. 147.

Ibn al-Haiṯam explains the use of the instrument in the following manner: "In order to investigate the nature of moonlight with this instrument, we stand opposite the moon with this instrument, put our eye to the small hole and move the ruler until we see the moon's orb at the same time through the hole and the slit. Then we move the first ruler with the two vanes up and down until we see one of the two ends of the gap, which is in the upper vane, together with the circumference of the moon's orb, to wit, on that side which is next to that edge: what remains is that which is covered by the slit, and that which is close to the other edge, in case there is an empty hole there, so that the circumference of the moon's orb is visible with the end of the covering parts. It is clear that with this adjustment the eye sees nothing of the moon except what can be seen through the gap, because what remains of the two vanes on each of the two sides of the gap subtends with the [**176**] small hole an angle which is not smaller than that angle which the diameter of the moon subtends from the eye. When we have done this, we remove the eye from the hole and put a small dense body (i.e. a shutter) opposite the hole (at the place, where the eye was); accordingly the light appears on it. In this case the light comes out of the hole and shines upon the body standing opposite. From this it follows that the light which leaves the hole with this arrangement comes only from that part of the moon which is seen from the gap. This is a sign of the fact that the light travels only in the direction of straight lines, in whose direction

[2] M. Schramm, *Ibn al-Hayṯams Weg*, op. cit., p. 146.
[3] v. Muṣṭafā Naẓīf, *al-Hasan b. al-Haitam*, op. cit., pp. 156-158; M. Schramm, *Ibn al-Hayṯams Weg*, op. cit., pp. 146 ff.

the eye sees what is lying on these lines, and in this condition of the hole none of the object appears besides that part which is only seen through the gap. It is clear that the light which is seen with this arrangement is only the light which proceeds from this part, which one sees through the gap. When the light emanating from the hole appears, the observer holds tightly the body on which the light is shining with this arrangement, placing upon the edge of the gap a dense body, moving it very gradually and observing the light coming out of the hole. This diminishes very gradually until it disappears. The same happens when the covering body is placed at the other edge of the gap and moves it gradually. Then too the light emerging becomes less and less until it disappears, and no light is visible since it has disappeared completely. As long as a part is free in the gap, the light that comes from it is perceptibly similar to this. From this it follows that the light of each part of the visible part of the gap proceeds towards the small hole, because if the light only proceeded from one part of the moon and not from the other parts, none of the light would disappear until the covering body reached up to that part. Yet when it has reached this part, the light proceeding from the hole would disappear suddenly and not gradually diminish; however, it does not disappear suddenly. From this observation it follows that the light proceeding from the small hole originates from the entire visible gap. Since this is difficult to observe, the diminution of the light which proceeds from the gap is not clearly perceived. Therefore it is necessary that the ruler is adjusted tightly and that which protrudes above the edge is covered, so that at the small hole only that part of the surface of the moon is visible which lies in the direction opposite this part of the gap. The light travels from the gap to the small hole and appears on the body which has been firmly fixed upright behind the hole. If it is desired to cover the gap from both the sides, until only a small part of it remains, so that the light proceeding from it is just noticeable and is not less than that which can be noticed (i.e. when the user is approaching the limit of perceptibility), a body with a small hole is placed upon the gap and thus covers the entire gap except for one part corresponding to this hole. It is in this case clear that the light which travels from the small first hole to the firm body that is behind it is the light from a small part of the surface of the moon, with only the very small part from which the light proceeds being included in the first hole. While this happens, the edges of the gap are opposite the surface of the moon, and only a part in the middle of the moon is observed."

"When a larger part of this gap is covered so that only a smaller part remains, the user sees a certain amount of the moon from the first hole and through that part of the gap which remains uncovered. It is the amount of the gap which the moon covers. It may be the smallest amount from which light is still noticeably emerging. It is clear that the light emerging from the two holes is only the light coming from this small part, since nothing else is visible through these two holes except this part of the moon. After that one must slowly and carefully move the covering body, which was placed on the gap, along the gap itself. Thus the uncovered part of the gap is changed. The part situated opposite it and the first hole will be another part of the moon than the first part. Then the covering body is moved up or down until the small hole which is [**177**] in the obscuring body makes the entire gap disappear. When this happens, the light always comes from the two holes in the same way."

"From these observations it follows that the light proceeds from the entire part of the moon which lies opposite the gap. After that the vertical ruler must be rotated in a circle by a very small amount until the gap is directed towards another part of the moon's surface which is parallel to the first part and adjacent to it. Then we find that the light again comes out of the hole in the same way as it came out of the first part. When we again cover this part gradually, the light diminishes gradually. When we place a covering body with a hole (aperture shutter) upon the gap, as was mentioned, and when we move it, we find that the light always comes out of both holes. If the vertical ruler is moved gradually to the right and to the left, until the visible surface of the moon disappears, the moon behaves in all these positions exactly alike. From this it follows that the light travels from all parts of the moon's surface to the small hole. The instrument is turned to many different positions and the light observed there as before. Even if many instruments are set up at different places at the same time, the same observations are always made."

"When the characteristics of moonlight are observed in this way, support must be provided during the observations by helpers (assistants), and when the light coming out of the small hole is observed, the ruler must be held firmly all the time so that it cannot move. Furthermore, the body on which the light emanating from the small hole appears must

be very close to the hole, and the observation of the emerging light must be done very carefully. Because the light coming from a small part is very weak, it is therefore necessary to search for it most carefully.

The observations must be conducted during the nights of the full moon. If it is ascertained that the condition for each point for which the light is observed and every time when observations are carried out, is exactly the same, then it follows from that the light travels from the entire surface of the moon to each opposite point. But when the light from the entire luminous area of the moon travels to each opposite point, then light travels to each opposite point from each point of the surface of the moon."[4]

"It is perhaps best to visualise the form of the shutter which Ibn al-Haytham recommends as a plate in which a slit has been made which intersects the gap of the objective sight. That this cannot be a device which also limits the width of this gap is shown to us particularly by the manner in which Ibn al-Haytham wants to see the width of this slit defined by the shifting of the shutters from both sides towards the middle."[5]

Our model was constructed according to the detailed description by Ibn al-Haiṯam.

Supplementary shutter

α'

Drawing from M. Schramm, *Ibn al-Haythams Weg*, p. 168.

[4] ibid, pp. 335-338 (reprint pp. 165-168).
[5] *M. Schramm, Ibn al-Haythams Weg, op. cit., p. 168.*

[178] Apparatus for the Observation of the Refraction of Light

In the seventh tract (*maqāla*) of his book of optics,[1] Ibn al-Haiṯam (d. after 432/1041) describes an instrument for experimenting with various cases of refraction (*inʿiṭāf*), in order to investigate the relations between the angle of incidence (*zāwiya ʿaṭfīya*), the angle of refraction (*zāwiya bāqiya*) and the angle of deflection (*zāwiya inʿiṭāfīya*). This description was rendered into German by Eilhard Wiedemann in 1884 from the Latin translation after comparing it with the Arabic original:[2]

"A circular and fairly thick copper disc is taken with a diameter of at least one ell. It must have a rim that stands vertically on its surface and is at least three fingers wide. In the middle of the back of the disc there must be a little round pillar (fig. 2 *b*) of at least three fingers' length, which stands vertically on the surface of the disc."

Our model:
Brass, engraved.
Diameter: 34 cm, suspended from a brass stand, so that it can be rotated. Glass container with lacquered brass frame (25 × 40 × 27 cm).
(Inventory No. E 2.03)

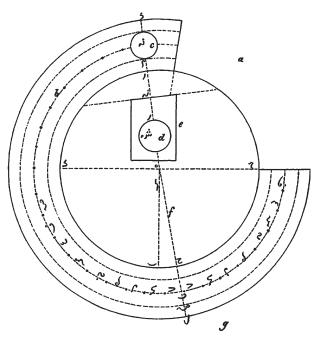



Fig. 1 from E. Wiedemann (after Ibn al-Haiṯam).

[1] Kamāladdīn al-Fārisī, *Tanqīḥ al-Manāẓir*, op. cit., vol. 2, pp. 115 ff.; Muṣṭafā Naẓīf Beg, *al-Ḥasan b. al-Haiṯam*, op. cit., pp. 685-693.

[2] E. Wiedemann, *Über den Apparat zur Untersuchung und Brechung des Lichtes von Ibn al Haiṯam*, in: Annalen der Physik und Chemie (Leipzig) N.F. 21/1884/541-544 (reprint in: *Gesammelte Schriften*, vol. 1, pp. 33-36 and in: Natural Sciences in Islam, vol. 33, pp. 111-114).

[**179**] “We attach this instrument to the lathe on which the turners turn their copper instruments, doing this in such a way that one of the tips of the lathe rests in the middle of the disc, the other in the middle of the small pillar, and we turn the lathe until the rims of the disc are completely circular and smooth inside and outside, and the little pillar is also circular. After that we draw two diameters perpendicular to each other on the inner surface of the instrument, then we mark a point on the base of the rim of the instrument whose distance from the end of one of the two diameters is one finger’s width. From this point we draw a third diameter through the middle of the disc.”

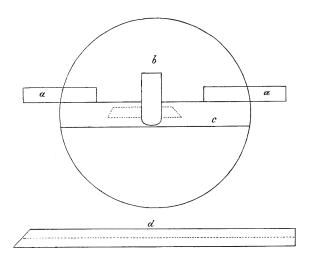
“Then we draw two lines on the rim, from the two ends of this diameter, perpendicular to the surface of the disc. On one of these two lines we mark three points, at a distance roughly of the length of half a barley corn from each other and turn on the lathe through these points three circles which are equidistant from each other, which of course also cut the opposite short line into three points that are equidistant from each other. Then the middle circle is divided into 360 degrees and, if possible, also into minutes. Into the rim a circular hole is drilled, the centre of which is the middle one of the three points mentioned above and the diameter of which is equal to the distance of the two outermost ones. Now we take a moderately thin, exactly rectangular flat piece of sheet metal d of the height of the rim and of about the same width. From the middle of one of the sides we draw a line that is perpendicular to this one, on which we mark three points which are equidistant from each other. When doing this, their distance a should be equal to the distances between any two circles on the rim. Then we drill a round hole into the plate, the centre of which corresponds to the middle one of the points above and the radius of which equals the distance a. We thereby obtain a hole which corresponds exactly to the one in the rim of the instrument. Thereafter is sought the mid point of the radius that connects the centre of the disc with the line on the rim on which the hole is, and through it a line vertical to the radius is drawn; along this, the small sheet metal is now attached, so that the middle of the same coincides exactly with the radius, the small opening in it then lying exactly opposite the one on the rim. The line connecting the centres of the two openings lies in the plane of the middle one of the two circles on the rim, lies parallel to the diameter on the disc and acts like the alidade of the astrolabe. After that out of the rim of the instrument that quarter is cut which is adjacent to the quarter in which the hole is situated and which is defined by the first two diameters, neatly smoothening the rim. After that a square piece of metal of a length of somewhat more than an ell is taken and the surfaces of the same are filed as perpendicular to each other as possible. In the middle of the same a hole perpendicular to one of the surfaces is drilled so that the pillar-like part mentioned above can be turned in it with some difficulty. Into this hole the pillar-like part is inserted. So much is cut off from the metal piece that it is flush with the rim of the disc and the cut ends are put onto the ends of the metal piece, connecting them with the same. It is expedient to push a small pin through the end of the little pillar jutting out from the opening in the square piece.”

“The measurements are conducted in such a way that the instrument is inserted into water up to the centre, tilting the connecting line of the two openings in various ways towards the horizon and defining the centre of the image under water just when the rays of the sun come through the two openings.”

Fig. 2 from E. Wiedemann (after Ibn al-Haiṯam).

[180] Apparatus

to Prove that the Light Rays of the Early Morning are in a Straight Line

Our model:
Wood, lacquered.
Two boxes (30 × 30 × 40 cm each), connected via a diagonal pipe (here the pipe is exposed, instead of passing through the connecting wall between the two chambers, as in Ibn al-Haiṯam).
A round opening on the upper part of the outer side of one of the boxes, directed towards the pipe.
The fronts are of acrylic glass.
(Inventory No. E 2.05)

Ibn al-Haiṯam considers the light of dawn as accidental. To demonstrate this, he conducts his experiment by means of two chambers separated by a wall. On the basis of the Leiden manuscript of Kamāladdīn al-Fārisī's *Tanqīḥ al-Manāẓir*,[1] the relevant text was translated into German by E. Wiedemann in 1912:[2]

[1] *Tanqīḥ al-Manāẓir*, op. cit., vol. 1, p. 33.
[2] *Zu Ibn al Haiṯams Optik*, in: Archiv für Geschichte der Naturwissenschaften und der Technik (Leipzig) 3/1911-12/1-53, esp. pp. 29-30 (reprint in: *Gesammelte Schriften*, vol. 1, pp. 541-593, esp. pp. 569-570, and in: Natural Sciences in Islam, vol. 33, pp. 165-217, esp. pp. 193-194); v. also Muṣṭafā Naẓīf Beg, *al-Ḥasan b. al-Haiṯam*, op. cit., pp. 158-160.

[**181**] "Take two neighbouring houses *A* and *B*, one of which lies to the east, the other to the west. Light should not be able to enter them. The eastern wall *O* of the eastern house A lies open to the sky (i.e. there is no house in front of it); in its upper portion a circular hole *K* is drilled, whose diameter is at least 1 foot and which is cut in the form of a cone *K*,[3] whose inner part is wider than its outer part, which is directed to the east. Into the common walls between the two houses two holes O_1 and O_2 are drilled which are opposite one another and are equal to the above-mentioned hole; they have the shape of a cylinder so that when a straight line is formed to connect one point of the outermost end of the first hole and the nearer point of the two edges of the two holes, it glides on to the surface of the cylindrical hole and reaches the western hole O_2. The two holes O_1O_2 must lie closer to the ground than the first hole *K* and in such a way that when someone looks into one of them they see the sky through the first one. The essential fact of the matter is that the wall is a body, so that the holes have a corresponding extension and therefore the light emerging from them cannot be diffused too much. Then a thread is stretched out which is fixed to a nail at the outermost edge of *K* so that it runs along the edge of the two holes O_1 and O_2; then it is straight. At the end of the thread a mark *f* is made. Then the observer goes into the house during a black dark night …"

"Then he observes the dawn (*ṣabāḥ*); when it appears he looks through the two holes until he sees the air shining. Then he carefully observes the place *f*. He then sees a faint trace of light there. As the light rises it becomes stronger, until it is clear and circular at both places (immediately near the hole and at *f*) and seems to be somewhat wider than the hole, corresponding to the diffusion of the light. If then one of the two holes is covered, its light is cut off from the place lying opposite, and if the straight extension between the hole and the light falling on it is cut by a thick body, it appears on this one and is cut off from the place where it falls (*f*). The same happens on the section between the upper hole and the lower one. If several holes are drilled into the western house which correspond to the specific (first) hole, a correspondingly large number of lights are found which become stronger inside the house, as we described just now. This (straight) extension can be ascertained with a straight staff. If curved extensions (i.e. places) which do not lie on the straight line are cut through a thick body, the light falling upon them does not disappear and does not appear on the dark body."

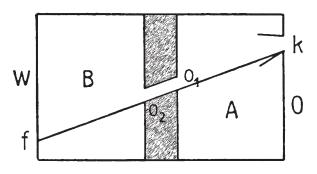
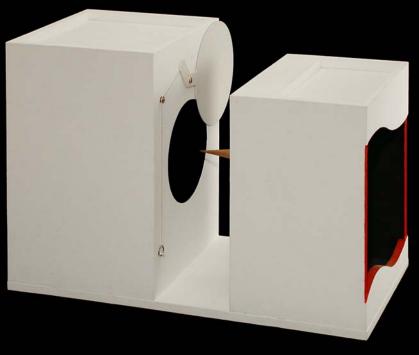
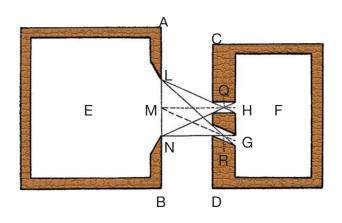
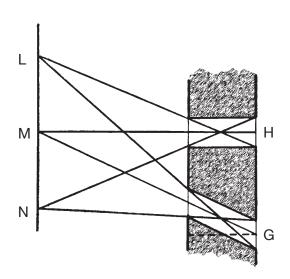
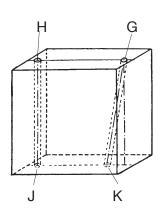



Fig. de E. Wiedemann.

Our model was made on the basis of the detailed description and sketch by E. Wiedemann (1912).

[3] Here we have corrected Wiedemann's translation.

[182] Apparatus to Prove that Accidental Light Moves in a Straight Line

Our model:
Wood, lacquered.
Total width 55 cm.
Left box with wooden cone and diagonal opening for the light, open on one side for demonstration purposes.
Right box with swivel-mounted shutter.
(Inventory No. E 2.04)

Figures after M. Naẓīf.

[**183**] The explanation of this experiment by Ibn al-Haiṯam is rather complicated. His text is very detailed, but the illustrations are missing in the extant manuscripts. Therefore the translation by E. Wiedemann[1] is not error-free either. Muṣṭafā Naẓīf, the eminent expert of Ibn al-Haiṯam's optics,[2] endeavoured to give an intelligible interpretation, based on Kamāladdīn al-Fārisī's commentary.[3] For our reconstruction, we relied on his description and his sketches. Leaving aside the fact that the experiment is rather difficult to conduct, this experimental apparatus is considered by Muṣṭafā Naẓīf to be one of the best examples of the high standard of the methods developed by Ibn al-Haiṯam.[4] He conducted his experiment by means of two chambers situated opposite one another at a distance of ca. 80 cm, with a door each but without any window. They are arranged in an east-west direction.

A cube of wood is prepared with a length of the sides of ca. 60 cm, corresponding to the thickness of the wall CD. Two opposite sides of the cube are divided by a line in the middle, parallel to the edges. On the lines two circles each (G, H and K, J) are drawn, with a diameter of ca. 4 cm and a distance of 4 cm (G, H, J) or of 8 cm (K), as the case may be, from the outer edge. Between H and J and between G and K the cube is drilled through exactly in the form of a cylinder in the diameter of the circles. Then it is fitted firmly into the wall CD, which faces the next chamber, which has the same diameter. After this a cone of wood with a base of 4 cm diameter and a height of 140 cm is prepared, corresponding to the distance between the walls of the two chambers plus the thickness of the wall CD. With the tip of the cone the centre M of the circle to be drawn with the radius LM is marked on the wall of the next chamber. Through the opening HJ bearings are taken for point L. It is the outermost point visible through the hole. The circle on the wall of the next chamber serves to make a round opening there. By means of this opening and the narrow openings in the opposite wall numerous observations are made in order to establish that accidental rays of light proceed in a straight line.[5]

[1] Zu Ibn al Haiṯams Optik, op. cit., pp. 33 ff. (reprint in: *Gesammelte Schriften*, vol. 1, pp. 573 ff., and in: Natural Sciences in Islam, vol. 33, pp. 197 ff.).
[2] *al-Ḥasan b. al-Haiṯam*, op. cit., pp. 160-165.
[3] *Tanqīḥ al-Manāẓir*, op. cit., vol. 1, pp. 33-39.
[4] M. Naẓīf Beg, *al-Ḥasan b. al-Haiṯam*, op. cit., p. 165.

[5] For a detailed description of Ibn al-Haiṯam's observations, I refer the reader to the study by Muṣṭafā Naẓīf.

[184] Camera Obscura

Model of wood:
42 × 36 × 37 cm. Steel frame: 90 × 60 × 93 cm.
Brass fixtures. Halogen lamp for demonstration.
(Inventory No. E 2.01)

The fact that the historiography of sciences in our times considers Ibn al-Haiṯam (b. ca. 354/965, d. after 432/1041)[1] to be the true inventor of the camera obscura was the result solely of the research on this subject done and inspired by Eilhard Wiedemann since the first decade of the 20th century. Before that a number of occidental scholars were considered its inventor, among them Roger Bacon (d. ca. 1290), Witelo (Vitellius, Vitellio, d. ca. 1280),[2] John Peckham (Pecham, d. 1292),[3] Levi ben Gerson (d. 1344),[4] Leone Battista Alberti (1404-1472),[5] Leonardo da Vinci (1452-1519), Francesco Maurolico (1494-1575)[6] or Giambattista della Porta (d. 1615).[7] Ibn al-Haiṯam dealt with the question of the camera obscura, probably not without the knowledge of earlier treatments by his Greek and Arab predecessors, in his fundamental work of optics (*Kitāb al-Manāẓir*[8]) and in two monographs, "On the image of solar eclipses" (*Maqāla fī Ṣūrat al-kusūf*[9]) and "On the light of the moon" (*Maqāla fī Ḍauʾ al-qamar*[10]).

[1] v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 5, pp. 358-374, vol. 6, pp. 251-261.
[2] George Sarton, *Introduction to the History of Science*, vol. 2, part 2, pp. 1027-1028.
[3] ibid, pp. 1028-1030.
[4] v. Otto Werner, *Zur Physik Leonardo da Vincis*, PhD thesis Erlangen 1910, p. 108; J. Würschmidt, *Zur Geschichte, Theorie und Praxis der Camera obscura*, in: Zeitschrift für mathematischen und naturwissenschaftlichen Unterricht (Leipzig and Berlin) 46/1915/466-476, esp. p. 468 (reprint in: Natural Sciences in Islam, vol. 32, pp. 20-30, esp. p. 22).
[5] v. O. Werner, op. cit., p. 107.
[6] E. Gerland, *Geschichte der Physik*, München and Berlin 1913, Erste Abteilung, p. 269; O. Werner, op. cit., p. 107.
[7] E. Gerland, op. cit., pp. 271-272.
[8] Vol. I, consisting of the first three treatises, was edited by ʿAbdalḥamīd Ṣabra, Kuwait 1983.
[9] v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 6, p. 257.
[10] ibid, p. 255.

[**185**] E. Wiedemann and the scholars inspired by him did not yet have access to the Arabic original of the *Kitāb al-Manāẓir*. The unreliable Latin translation, published as long ago as 1572 by Friedrich Risner,[11] is far from giving a precise idea of the significance of the treatment of the subject contained in it. Therefore Wiedemann's group was inclined to assume that "a very detailed theory of the camera obscura, that is to say in its application to terrestrial conditions", was given only by the commentator of the *Kitāb al-Manāẓir*, Muḥammad b. al-Ḥasan Kamāladdīn al-Fārisī (d. ca. 720/1320).[12] We have only learnt the real state of affairs thanks to the excellent, extensive studies by Muṣṭafā Naẓīf[13] and Matthias Schramm.[14]

Schramm[15] finds a clear description of the camera obscura in the *Kitāb al-Manāẓir* in the context of the theory of light and colour. Here Ibn al-Haiṯam gives "special advice for realising the camera obscura effect experimentally. This passage containing the description of a camera obscura in the strict sense of a darkened room, equipped with an aperture shutter in which the observer stays was omitted by the translator of the Risner edition, a sign that he or his presumed readers were not especially interested in the experimental side."

"Ibn al-Hayṯham writes: 'It is possible that this state of affairs is easy to observe systematically, at any given point of time; and this can be done by the observer going into any chamber during a dark night. The chamber should have a door with two wings. He (the observer) should take several candlesticks and fix them separately opposite the doors. Then the observer should enter the chamber and close the doors again; but he should leave a gap between the two wings of the door and open a small space between them (the wings of the door). Then he should watch the wall of the chamber that is opposite the door. Because on it he will find the images of light, separate from one another, according to the number of those candlesticks, viz. in such a way that they (the images of light) enter from the gap, whereby each individual image is opposite a particular one of those candlesticks. When the observer then gives the order that one of those candlesticks should be hidden by a screen, the light which is opposite that candlestick disappears. And when the screen is removed again, that light comes back.'

'When the observer then covers the gap of the door, leaving only a small drillhole in it, and when this hole is opposite the candlesticks, then he will find on the wall of the chamber once again images of light, separate from each other, according to the number of those candlesticks, and then each individual one of them will depend on the dimensions of the drillhole'."[16]

On this Schramm remarks, inter alia: "Ibn al-Hayṯham calls the device described by him *bayt muẓlim*, dark chamber. Here we encounter the expression from which ultimately our term camera obscura is derived."[17] Therefore there should be no doubt any longer that the idea prevalent until the beginning of the 20th century in the historiography of sciences that the camera obscura was invented by European scholars is not tenable any more. Their acquaintance with Ibn al-Haiṯam's description of the camera obscura need not necessarily have been a consequence of the inexact [**186**] anonymous Latin translation of the *Kitāb al-Manāẓir*,[18] which was probably made in the 12th or 13th century.

The knowledge of the camera obscura from the Arab-Islamic world may have also reached one or the other of those scholars through other sources or through personal contacts. Let us bear in mind that, after Ibn al-Haiṯam, many scholars of the Islamic world also occupied themselves for centuries with optical questions, including the camera obscura,[19] and let us not forget the high level which optics reached in the work of Kamāladdīn al-Fārisī, the commentator of Ibn al-Haiṯam.[20]

[11] *Opticae thesaurus Alhazeni*, Basel 1572.

[12] E. Wiedemann, *Über die Erfindung der Camera obscura*, in: Verhandlungen der Deutschen Physikalischen Gesellschaft 1910, pp. 177-182, esp. p. 177 (reprint in: *Gesammelte Schriften*, vol. 1, pp. 443-448, esp. p. 443, and in: Natural Sciences in Islam, vol. 34, pp. 207-212, esp. p. 207); J, Würschmidt, op. cit., p. 468; O. Werner, op. cit., pp. 110-111.

[13] al-Ḥasan b. al-Haiṯam, *buḥūṯuhū wa-kušūfuhu l-baṣarīya*, 2 vols., Cairo 1942-1943 (reprint: Natural Sciences in Islam, vols. 35-36, Frankfurt 2001).

[14] *Ibn al-Hayṯhams Weg zur Physik*, Wiesbaden 1963.

[15] ibid. p. 210, cf. *Kitāb al-Manāẓir*, vol. 1, Kuwait 1983, pp. 170-171.

[16] Here we omitted the Arabic terms which Schramm added in parenthesis.

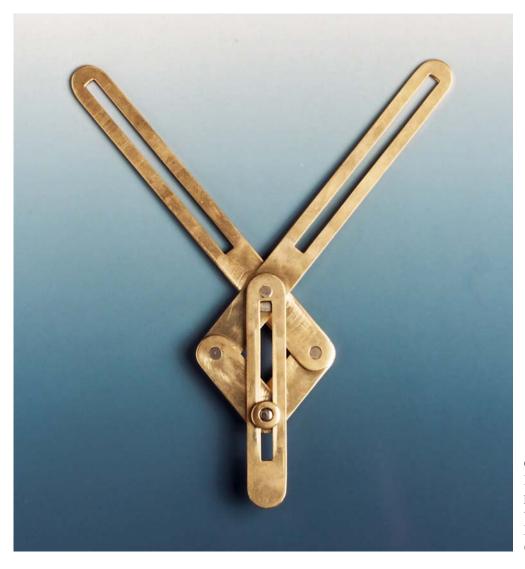
[17] M. Schramm, op. cit. pp. 211-212.

[18] See above, note 11; G. Sarton, *The tradition of the optics of Ibn al-Haitham*, in: Isis 29/1938/403-406 (reprint in: Natural Sciences in Islam, vol. 34, pp. 69-72).

[19] v. E. Wiedemann, *Arabische Studien über den Regenbogen*, in: Archiv für die Geschichte der Naturwissenschaften und der Technik (Leipzig) 4/1913/453-460 (Nachdruck in: *Gesammelte Schriften*, Bd. 2, S. 745-752 and in: Natural Sciences in Islam, Bd. 34, S. 165-172).

[20] Josef Würschmidt, *Dietrich von Freiberg: Über den Regenbogen und die durch Strahlen erzeugten Eindrücke*, Münster

Moreover, we must also take into account—not only in this case—translations of Arabic, Persian and Turkish books, which did not find further dissemination, or also of individual use of such books whose content became known to one scholar, in full or in part, through the mediation of a person who was familiar with the languages concerned. In the course of his study of the process of the reception of Arabic-Islamic sciences in Europe, the author of these lines gained the impression that many important books and maps as well as technical or scientific devices and instruments from the Arabic-Islamic world reached Italy in this manner through personal contacts, particularly also through zealous and focused mediation of ecclesiastical scholars from Byzantium before and after the conquest of Constantinople.

In this context it is interesting to note that Leonardo da Vinci seems to have used Ibn al-Haiṯam's *Kitāb al-Manāẓir* long before the Latin translation in the edition by Risner (1572) was accessible. The Italian scholar Enrico Narducci[21] has demonstrated that Leonardo must have used an already existing Italian translation of Ibn al-Haiṯam's work. Otto Werner,[22] who studied Leonardo's physics, adds: "Since Leonardo mentions what is known as Alhazen's problem, to find the point of reflection with spherical, cylindrical and conic mirrors, and since he also attempts to give the solution and, furthermore, as was already mentioned, gives the same data about the stars, particularly Mercury and Venus, as Ibn al Haiṯam does, it is very probable that Leonardo knew and used Ibn al Haiṯam."O. Werner[23] even found indications that Leonardo also knew the optics of Kamāladdīn al-Fārisī, the commentator of Ibn al-Haiṯam's work. In connection with the reversal of the image which results from an illuminated object, he says: "It is astonishing how exactly a figure in Codex Atlanticus on fol. 238r-b … follows that of Kamâl al Dîn al Fârisî. Therefore it appears as if his work was known in the Occident. This is also supported by the close connections between the rainbow theorem of Theodosius Saxonicus and that of Kamâl al Dîn al Fârisî." The conviction voiced by O. Werner in connection with the question of the camera obscura should also be noted: "According to that, despite Müntz's view, Leonardo probably took over the camera obscura not only in its initial stage, but also in its developed form, and added nothing of his own."[24]

1914, p. 2.

[21] *Intorno ad una traduzione italiana fatta nel secolo decimoquarto, del trattato d'ottica d'Alhazen …* in: Bullettino di bibliografia e di storia delle scienze matematiche e fisiche (Rome) 4/1871/1-48, 137-139 (reprint in: Natural Sciences in Islam, vol. 34, pp. 1-51); O. Werner, *Zur Physik Leonardo da Vincis*, op. cit., p. 137.

[22] O. Werner, op. cit., p. 137.

[23] ibid, p. 111.

[24] ibid, p. 111.

Our model:
Brass, five parts, pivoted to one another with rivets.
Length: 26 cm.
(Inventory No. D 1.20)

[187] The ‹Problem of Ibn al-Haiṯam› (Problema Alhazeni)

The well-known optical-mathematical "problem of Ibn al-Haiṯam" is discussed here because of the fact that Leonardo da Vinci (1452-1519) constructed an apparatus for its mechanical-graphical solution.[1] In 1910 Otto Werner[2] expressed his view that Leonardo seems to have had amongst his sources the large book on optics (*Kitāb al-Manāẓir*) by Ibn al-Haiṯam and that from this he knew of the problem of finding the point of reflection with spherical, cylindrical and conical mirrors and attempted to solve it. Werner surmised that Leonardo used Ibn al-Haiṯam's book in an Italian translation (see above p. 186).

[188] The problem dealt with in the 5th tract (*maqāla*) of Ibn al-Haiṯam's book involves defining the point of reflection on spherical, cylindrical, conical, convex as well as concave mirrors when the two values of "eye" and "luminous point" are

[1] *Leonardo da Vinci. Das Lebensbild eines Genies*, Wiesbaden and Berlin 1955, p. 410.
[2] *Zur Physik Leonardo da Vincis*, op. cit., p. 137.

given.[3] “The problem in its general form leads analytically to an equation of the 4th degree.”[4]
In the West the problem was included by Vitello in his book on optics as early as 1270. His detailed treatment of the subject was “copied or rephrased[5]” from the Latin translation of Ibn al-Haiṯam’s *Kitāb al-Manāẓir*. After Leonardo da Vinci, it was Isaac Barrow (1669) who occupied himself with the problem. Then René François de Sluse (1673), Christiaan Huyghens (1695), Guillaume François Antoine d’Hospital (1720), Robert Simson (1st half 18th c.), Abraham Gotthelf Kaestner (1719-1800), Thomas Leybourn (1817) and Charles Hutton (1737-1823) attempted to solve the problem.[6] Kaestner wanted “to solve the problem without the construction of the hyperbola, which had no practical use.”[7] Five years after Kaestner, William Wales published a study “in which Alhazen’s problem is used as an example of a method of solving equations of higher degrees through approximation with the help of trigonometric functions.”[8]

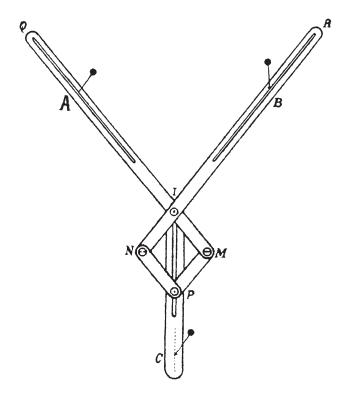



Fig. from Leonardo da Vinci.
Das Lebensbild eines Genies, op. cit., p. 410.

[3] v. Kamāladdīn al-Fārisī, *Tanqīḥ al-manāẓir*, op. cit., vol. 1, pp. 497 ff.; Muṣṭafā Naẓīf Beg, *al-Ḥasan b. al-Haiṯam*, op. cit., pp. 551 ff.; Paul Bode, *Die Alhazensche Spiegelaufgabe in ihrer historischen Entwicklung nebst einer analytischen Lösung des verallgemeinerten Problems*, in: Jahresbericht des Physikalischen Vereins zu Frankfurt am Main 1891-92 (1893), pp. 63-107 (reprint in: Islamic Mathematics and Astronomy, vol. 57, pp. 66-110).
[4] M. Schramm, *Ibn al-Haythams Stellung*, op. cit., 20a.
[5] P. Bode, *Die Alhazensche Spiegel-Aufgabe*, op. cit., pp. 77-78 (reprint pp. 80-81).
[6] Marcus Baker, *Alhazen’s Problem. Its Bibliography and an Extension of the Problem*, in: American Journal of Mathematics (Baltimore) 4/1881/327–331 (reprint in: Islamic Mathematics and Astronomy, vol. 57, Frankfurt, 1998, p. 61–65); M. Schramm, *Ibn al-Haythams Stellung*, p. 20a.
[7] P. Bode, *Die Alhazensche Spiegel-Aufgabe*, p. 81 (reprint p. 84).
[8] Ibid., p. 82 (reprint p. 85).

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Science and Technology in Islam

IV

SCIENCE AND TECHNOLOGY IN ISLAM

VOLUME IV

Catalogue of the collection of instruments of the Institute for the History of Arabic and Islamic sciences

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7. MEDICINE • 8. NAVIGATION
9. MINERALOGY

2010

Institut für Geschichte der Arabisch–Islamischen Wissenschaften
an der Johann Wolfgang Goethe-Universität
Frankfurt am Main

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Chapter 7

Medicine

We do not seem to possess the prerequisites to draw definite conclusions about many problems. Even so, it is important to state our views on these matters in accordance with our abilities. For, it is not ruled out that discoveries may be made later, through which certainty can be achieved in many matters which we cannot solve today.

Ibn Rušd (Averroes, d. 595/1198)

INTRODUCTION

1. Medical Instruments

As in the fields of mathematics, astronomy, physics, chemistry, zoology, botany and geography, Arabic literature provides us in the field of medicine also with examples which show that the people in the Arabic-Islamic cultural area were well acquainted as early as the 3rd/9th century with the method of depicting human figures to illustrate medical matters. It is beyond doubt that in this process the Arabic-Islamic scholars and illustrators were following the tradition of their Greek predecessors. The only illustrations known to me in the field of medicine dating from the 3rd/9thcentury are to be found in the Cairo manuscript[1] of the well-known «Ten Treatises on the Eye»[2] by Ḥunain b. Isḥāq (d. 260/873)[3]: «Five illustrations of the eye, three of them identical, adorn the manuscript; these are painted in black and red water colours; the vitreous body of the eye was painted in some other colour which apparently attacked the heavy paper, because it disintegrated in all illustrations exactly where it corresponds to the vitreous body.»[4] Published in 1910 by M. Meyerhof and C. Prüfer, the illustrations were made known to a wider public in the edition of the entire book published by Meyerhof[5] in 1928.

From the point of view of the development of the history of medicine it is highly significant that towards the end of the 4th/10th century the Andalusian physician Abu l-Qāsim Ḫalaf b. ʾAbbās az-Zahrāwī[6] already describes and illustrates more than 200 instruments in the 30th treatise of his book on surgery which encompasses the entire art of healing. When he laments the neglect of surgery in his country and age,[7] stating that from the books of his predecessors just a few illustrations were known, we should understand this lament in a limited sense and see it rather in relation to a narrow geographical area. At any rate az-Zahrāwī does not neglect to often mention the provenance and the inventor of an instrument which he describes. He also stresses that, even though there are innumerable medical instruments, a capable surgeon ought to be in a position at any time to develop new instruments if need be.[8]

Whatever may have been the motivation for the author of the *K. at-Taṣrīf* and from whatever sources and circles the material covered may originate, az-Zahrāwī is, according to our knowledge, the first and perhaps even the only surgeon in the history of medicine before modern times, to describe more than 200 instruments (which, according to his own account, he did not invent) and to provide these descriptions with illustrations. The importance of his achievement is even enhanced by numerous illustrations of scenes of treatment where the use of the instruments is depicted.

[1] Dār al-Kutub al-Qaumīya, ms. Taimūr, ṭibb 100.

[2] *Tarkīb al-ʿain wa-ʿilaluhā wa-ʿilāǧuhā ʿalā raʾy Ibuqrāṭ wa-Ǧālīnūs wa-hiya ʿašr maqālāt*, pp. 314-318 of the manuscript.

[3] v. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 3, pp. 247-256.

[4] M. Meyerhof and C. Prüfer, *Die Augenanatomie des Ḥunain b. Isḥâq. Nach einem illustrierten arabischen Manuskript herausgegeben*, in: Archiv für Geschichte der Medizin (Leipzig) 4/1910/163-191, esp. p. 165 (repr. in: Islamic Medicine, vol. 23, pp. 45-73, esp. p. 47).

[5] *The Book of the Ten Treatises on the Eye ascribed to Hunain ibn Ishâq (809-877 A.D.)* … edited … by Max Meyerhof, Cairo 1928 (repr. Frankfurt 1996 as Islamic Medicine, vol. 22).

[6] v. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 3, pp. 323-325.

[7] *at-Taṣrīf li-man ʿaǧiza ʾan at-taʾlīf*, facs. ed. Frankfurt 1986, vol. 2, p. 461; *Albucasis. On Surgery and Instruments. A Definitive Edition of the Arabic Text with English Translation and Commentary*, by M. S. Spink and G. L. Lewis, London 1973, p. 3.

[8] *at-Taṣrīf*, facs. ed., vol. 2, p. 4; *Albucasis. On Surgery and Instruments*, op. cit., p. 285.

[**4**] Az-Zahrāwī and his book on surgery enjoyed and continue to enjoy in the Occident a much greater fame than in the Islamic world. The text was translated by Gerard of Cremona into Latin barely 200 years after it was written. It was also translated into Hebrew and into Provençal. Soon thereafter the first important work on surgery, the *Cyrurgia* by Guglielmo da Saliceto[9] (ca. 1275), appeared in the Occident. This was followed in the next century by the much more voluminous work by Guido de Cauliaco[10] (Guy de Chauliac, d. ca. 1368). Of course, the books by Abū Bakr ar-Rāzī (d. 313/925), ʿAlī b. al-ʿAbbās al-Maǧūsī (last quarter of the 4th/10th cent.) and Abū ʿAlī Ibn Sīnā (d. 428/1037) had a greater influence on the two western works than az-Zahrāwī's book. The importance of the 30th treatise of his book for the development of the new surgery in Europe, which began in the 13th century, seems to have lain more in the varied descriptions and illustrations of the medical instruments and scenes of medical treatment. It is highly astonishing to see how widely the manuscripts of the translation of az-Zahrāwī's surgery are disseminated in European libraries. To these should be added the incunabula, the first of which appeared in 1497. Since the Basel edition of 1541, az-Zahrāwī's treatise has also circulated under the title *Methodus medendi certa, clara et brevis*.

The study of az-Zahrāwī's surgical treatise from the point of view of Arabic studies and history of medicine began with the *Albucasis de Chirurgia* by Johannes Channing (Oxford 1778), in which he translated the text into Latin on the basis of the two Oxford manuscripts, Huntington 156 and Marsh 54, together with their illustrations. Later, in 1861, Lucien Leclerc[11] published a successful French translation with plates containing his copies of the illustrations of 172 instruments. He relied primarily on a Parisian manuscript which he described as «le manuscript d'Abulcasis de la bibliothèque de la rue Richelieu»; besides Channing's work and the Latin manuscripts, he consulted one more Arabic manuscript which he had «discovered» in Algeria. In 1898, in the first volume of his *Geschichte der Chirurgie* und ihrer Ausübung, E. Gurtl[12] included a summary of the French translation by Leclerc together with 102 of Leclerc's illustrations of instruments.

In 1918, in the second part of his *Beiträge zur Geschichte der Chirurgie im Mittelalter*, Karl Sudhoff[13], compiled «the illustrations of instruments of the Latin Abulqâsim-manuscripts of the Middle Ages». There he reproduced more than 200 illustrations.

It is also of interest for the history of medicine that at least two manuscripts of the Latin translation contain coloured illustrations of scenes of medical treatment, namely the manuscript in the Austrian National Library, Vienna, with the shelf mark S.N. 2641 and the Cod. 15 of the University Library in Budapest, and also, the Turkish version prepared in 1465 by Šerefeddīn Ṣabuncuoġlu for the Ottoman ruler Meḥmed Fātiḥ. Both the Vienna codex[14] with 68 illustrations and the Paris codex (MS suppl. turc 693) of the Turkish version[15] with 140 illustrations have been made accessible in facsimile editions in recent years.

[**5**] Eva Irblich, who edited the Latin facsimiles, deals in her informative introduction with the provenance of the miniatures by comparing the pictures of the Latin translation and of the Ottoman version: «The 'naive' Turkish miniatures of surgery of Charaf ed-Din in MS suppl. turc 693 in the Bibliothèque nationale at Paris demonstrate the simplicity of the pictorial representation of the medical text where the figure of the physi-

[9] v. G. Sarton, *Introduction to the History of Science*, vol. 2, part 2, Baltimore 1931, pp. 1078-1079.

[10] ibid, vol. 3, part 2 (1948), pp. 1690-1694.

[11] *La chirurgie d'Abulcasis* (Arabic: *Abu l-Qāsim Ḫalaf b. ʿAbbās az-Zahrāwī*) traduite par …, Paris 1861 (repr. Frankfurt 1996 as Islamic Medicine, vol. 36).

[12] Berlin 1898 (repr. Hildesheim 1964), pp. 620-648 with plates IV and V.

[13] *Beiträge zur Geschichte der Chirurgie im Mittelalter. Graphische und textliche Untersuchungen in mittelalterlichen Handschriften*, 2nd part, Leipzig 1918, pp. 16-75 (repr. in: Islamic Medicine, vol. 37, pp. 166-247).

[14] *Abu'l Qāsim Ḫalaf ibn ʿAbbās al-Zahrāuī, Chirurgia. Lateinisch von Gerhard von Cremona. Vollständige Faksimile-Ausgabe im Originalformat von Codex Series Nova 2641 der Österreichischen Nationalbibliothek, commentary by Eva Irblich; and Chirurgia Albucasis* (facsimile), Graz 1979.

[15] Šerefeddin Sabuncuoğlu, *Cerrāḥiyyetü 'l-Ḫāniyye* ed. Ilter Uzel, 2 vols. (transcription of the text and facsimile), Ankara 1992. The illustrations of the manuscript were published, some in colour but most of them in black and white, with French explanations by P. Huard and M. D. Grmek, *Le premier manuscrit chirurgical turc rédigé par Charaf ed-Din (1465) et illustré de 140 miniatures*, Paris 1960.

cian and that of the patient are drawn mainly from the front next to each other and not as interacting with one another. Here the differences between an Oriental miniature drawn in two dimensions in a decorative and flat style and an Occidental painting delineated with plasticity, depicting a scene with a three-dimensional or decorative background stand out most clearly.»[16]

«The dark skin colour of the figures, certain architectural elements such as the tent, the coffered wall or the round cupolas and the figure of the physician with a turban lead to the conclusion that the miniatures could go back to Arabic models. However, other elements such as the curtains, the flat cupolas, sculptures on pillars as bearers of cupolas or of curtains recall in their pictorial idiom components of the paintings of antiquity. Other pictorial elements, such as those of the human figures, the gothic architecture, the beginnings of landscape painting or of the two-dimensional decorative background of the pictures, reflect the southern European style of painting, which, despite its individuality, could be seen as part of the south Italian style of painting.»[17]

However, «the area of origin of the Latin version of the text in the school of translators of Toledo is more closely related, and it is also possible that the painting of the manuscript was influenced by antiquating and orientalizing stylistic elements of Moorish Spain.»[18]

Concerning Eva Irblich's informative analysis, I wish to clarify the following. In contrast to the Latin translation with its 68 illustrations, the Turkish version of 870/1465 offers roughly 140 miniatures of medical scenes. Moreover, the Latin version does not contain any illustrations of medical instruments. Leaving this aside, there is nevertheless so much agreement in both versions, not only in the depiction of the medical scenes, but also in the text that a common origin can be assumed. We can be sure of the fact that a copy commissioned by the author was provided with qualitatively good or at least adequate illustrations of instruments and medical scenes. Usually such tasks were executed by professional painters who belonged generally to the minority groups. It is, no doubt, possible that the illustrations deviated from the original in the course of time through repeated copying before, during and after the translation. I am inclined to think that the miniatures of the original were of a tolerably good quality.

Among the models of ophthalmological instruments in our collection, there are several that were not produced according to the illustrations of the *Taṣrīf* by az-Zahrāwī, but after the drawings from the *Kitāb al-Kāfī fi l-kuḥl* by Ḫalīfa b. Abi l-Maḥāsin al-Ḥalabī (written before 674/1275). This book, of which two manuscripts[19] are extant, was studied and translated into German by Julius Hirschberg.[20] In his descriptions of the instruments, Ḫalīfa included two plates of illustrations which are reproduced below from the Istanbul manuscript of the Yeni Cami collection. Moreover, in Ḫalīfa's book there is also an illustration of the optic nerve crossing which could originally go back to ʿAmmār b. ʿAlī al-Mauṣilī's (4th/10th cent.) ophthalmological work (see below, p. 27).

[16] Abu'l Qāsim Ḫalaf ibn ʿAbbās al-Zahrāuī, *Chirurgia*, op. cit., commentary p. 31a.
[17] ibid, pp. 31b-32a.
[18] ibid, p. 32a.

[19] Istanbul, Yeni Cami 924 and Paris, Bibliothèque nationale, ar. 2999; v. C. Brockelmann, *Geschichte der arabischen Litteratur*, suppl. vol. 1, p. 899.
[20] *ʿAmmār b. ʿAlī al-Mauṣilī: Das Buch der Auswahl von den Augenkrankheiten. Ḫalīfa al-Ḥalabī: Das Buch vom Genügenden in der Augenheilkunde. Ṣalāḥ ad-Dīn: Licht der Augen. Aus arabischen Handschriften übersetzt und erläutert* by J. Hirschberg, J. Lippert and E. Mittwoch, Leipzig 1905 (repr. Frankfurt 1996, Islamic Medicine, vol. 45); cf. J. Hirschberg, *Geschichte der Augenheilkunde*, Leipzig 1908, pp. 150-153.

Ophthalmological instruments from the *Kitāb al-Kāfī fi l-kuḥl* by Ḫalīfa b. Abi l-Maḥāsin al-Ḥalabī (written before 674/1275), from the Istanbul manuscript of the Süleymaniye Kütüphanesi, Yeni Cami 924.

2. Series of Anatomical Pictures

There are extant several series of five or six pictures each from Islamic medicine which attracted scholarly interest in the first decade of the 20th century. I have in mind particularly the illustrations of the book *Tašrīḥ-i Manṣūrī* by the Persian physician Manṣūr b. Muḥammad b. Aḥmad b. Yūsuf[1] from the late 8th/14th century. The illustrations in the book, which had been published several times in India since 1848, were studied by K. Sudhoff[2] in connection with his investigations into the anatomical illustrations. The pictures show diagrams of the bone system, the nerve system, the muscles, veins and arteries in the human body and the artery system of a pregnant woman. Sudhoff came to know of other pictorial representations, certainly older, of the bone system, the system of veins, muscles and arteries from the Oxford manuscript[3] of the *Ḏaḫīra-i Ḫwārazmšāhī* by Ismāʿīl b. Ḥasan b. Aḥmad al-Ǧurǧānī (d. 531/1137 or 535/1141). While comparing the pictures and the texts of the Persian manuscripts with the corresponding material in Occidental books, Sudhoff comes to the conclusion that the series of anatomical diagrams and their texts must have reached the Occident outside Spain at two different periods of time and perhaps through two different channels. He sees an important point for differentiation in the fact that the 13th century manuscript from Provence, now preserved in Basel, is the only manuscript to contain a diagram of a skeleton, a diagram of the female genital organs (without a drawing of the embryo) and a legend which is added to the skeleton.[4] Moreover, he discovers that both the diagram of the skeleton with the legend and the drawing of the female genitalia (here with a sketch of the embryo) appear in the Persian book of anatomy.[5] He states that the group of those Latin manuscripts which are different from the Basel family of manuscripts had their precursors in a codex of 1154 in the cloister at Prüfening (near Regensburg) and another one in the cloister at Scheyern (ca. 1250).[6] He is of the view that they show «such a clearly discernible agreement that a rather close connection between the two must be assumed.» But, he asserts, it is impossible that the Prüfening codex could have served as a model for the younger codex.[7] From this he concludes that the text from Provence, preserved in Basel, «has been combined from two distinct compilations of the 11th and 12th century which originated in Salerno»,[8] and comes to the following conclusion: «There is a close connection between the pictures from Prüfening, Scheyern and Oxford. I assume that they date from Antiquity and came down to us via Byzantium. The pictures from Provence preserved in Basel also originated in Antiquity, but perhaps their path of transmission was quite different.»[9]

Towards the end of the study Sudhoff expresses his views on the origin of the Persian illustrations: «It seems to me that, also through Arab medicine, the Persian manuscripts at London and Oxford point to a path of transmission of technical diagrams of anatomy [**8**] from Antiquity which perhaps goes back to those very same diagrams from Alexandria, of which we have already received distorted tidings in Occidental written records – perhaps! However, we do not yet have the faintest idea of how many

[1] Adolf Fonahn, *Zur Quellenkunde der persischen Medizin*, Leipzig 1910 (repr. Leipzig 1968), pp. 3-4; C. A. Storey, *Persian Literature*, vol. 2, part 1, London 1958, repr. 1972, pp. 225-227; Āġā Buzurg aṭ-Ṭahrānī, *aḏ-Ḏarīʿa ilā taṣānīf aš-šīʿa*, vol. 4, Teheran 1360/1941, pp. 184-185.

[2] *Ein Beitrag zur Geschichte der Anatomie im Mittelalter, speziell der anatomischen Graphik nach Handschriften des 9. bis 15. Jahrhunderts* (= Studien zur Geschichte der Medizin, Heft 4, Leipzig 1908), section 5: *Eine anatomische Sechsbilderserie in zwei persischen Handschriften*, pp. 52-72; E. Seidel and K. Sudhoff, *Drei weitere anatomische Fünfbilderserien aus Abendland und Morgenland*, in: Archiv für Geschichte der Medizin (Leipzig) 3/1910/165-187 (repr. Islamic Medicine, vol. 93, Frankfurt 1997, pp. 99-123).

[3] MS Fraser 201, Bodl. 1576, v. *Cat. of Pers., Turkish, Hindûstânî* … Mss., ed. Hermann Ethé, vol. 1, Oxford 1889, columns 951-952; v. K. Sudhoff, *Ein Beitrag*, op. cit., p. 52: «The six anatomical diagrams are to be found … on the flyleaves at the end of the second volume.»

[4] *Ein Beitrag zur Geschichte der Anatomie im Mittelalter*, op. cit., p. 29.

[5] *Drei weitere anatomische Fünfbilderserien*, op. cit., p. 187 (repr., op. cit., p. 121).

[6] *Ein Beitrag zur Geschichte der Anatomie im Mittelalter*, op. cit., p. 3.

[7] ibid, p. 3.

[8] ibid, p. 23.

[9] ibid, p. 28.

groups of anatomical illustrations may have been made in Antiquity and how many may have been handed further down …»[10]

In a study dealing with the same subject, which was published two years later and mentions E. Seidel as a co-author, Sudhoff concludes: «But today it can already be said with the utmost probability, it can almost be asserted with historical evidence, that these illustrations together with the text must be based on a short illustrated anatomical textbook in Greek, which was written in Alexandria and was provided with schematic drawings, probably after available models. The transmitted Latin text is completely free from Arabic influence, therefore it originates directly in the Occidental tradition from Antiquity. This text together with its illustrations was, of course, also known to the Arabs, but since the anatomical drawings could not be handed down for religious considerations, the text also is difficult to locate. But probably that will happen some day.»[11]

Sudhoff explains his notion of an ancient illustrated text on anatomy that reached the Occident directly and without any intervention by the Arabic-Islamic culture area in the following manner: «The strict school of thought of Islam to which all our Arabic authors on medicine belong, namely that of the Sunnis, made it impossible to preserve and hand down to us through further copying the Alexandrian anatomical drawings which, undoubtedly, must have been known to these authors as well ….»[12]

«The more liberal school of thought of the Persian Shiites, for whom the drawing of a human figure and thus anatomical drawings were not completely prohibited, intervenes in the transmission quite successfully, with its own contribution. Because, however much these illustrations (e.g. in the drawing of the liver) deviate from the other paths of tradition, they also point to Alexandria, even though perhaps to a different author or to another period of Alexandrian medicine. Nothing definite can be said about this at this point. Did Manṣūr ibn Muḥammad ibn Aḥmad change much in the drawings that were available to him or that he used? I believe he changed hardly anything, but through how many competent and through how many more incompetent hands had these illustrations passed, since the time they were first drawn on sheets of papyrus in Alexandria!»[13]

I wish to say a few words on Sudhoff's explanations or hypotheses and offer my own explanation. There is no doubt that the Arab physicians adopted the science of medicine primarily from the Greeks. They make no secret of it and in their books mention their sources with a precision unknown in other culture areas. It has not yet been clearly established how widely spread anatomical illustrations were among the Greeks. If such illustrations reached the physicians of the Arabic-Islamic world, we must assume that, like the development of medical knowledge as a whole, they too did not remain in the same state as they had been received. A full investigation of this still awaits to be done. At the moment we know of only the three illustrations of the anatomy of the eye which Ḥunain b. Isḥāq passed on to us on the basis of Galen's work.

But if we then encounter some anatomical sketches of the human body in Latin and also Persian manuscripts, and if both have obviously some connection with each other, then we are not justified in regarding them as unrelated loans from Greek sources. If one of those Latin manuscripts dates from 1154 and is preserved in a south Frankish cloister, then the present level of knowledge of the history of development of medicine allows us to connect the content of that manuscript [**9**] with those activities that began in Salerno in the first half of the 11th century through the person of the converted Arab Constantinus Africanus[14] (ca. 1015-1087) and through the Arabic books which he brought with him, translated and circulated, some of them under a different name. The many books that Constantinus Africanus brought with him included the voluminous textbook of medicine by ʿAlī b. al-ʿAbbās al-Maǧūsī (4th/10th cent.), in which as many as 110 chapters are devoted to anatomy and

[10] K. Sudhoff, *Ein Beitrag*, op. cit., p. 72.

[11] *Drei weitere anatomische Fünfbilderserien*, op. cit., p. 185 (repr., op. cit., p. 119).

[12] ibid, p. 186 (repr., p. 120).

[13] ibid, pp. 186-187 (repr., pp. 120-121).

[14] A large part of the studies on Constantinus Africanus and on the medicine at Salerno was reprinted in: Islamic Medicine, vol. 43, Frankfurt 1996, v. also Heinrich Schipperges, *Die Assimilation der arabischen Medizin durch das lateinische Mittelalter*, Wiesbaden 1964, pp. 17-54.

surgery.[15] It is highly probable that a copy of this work with anatomical drawings reached Salerno. Incidentally, it may be mentioned that the book circulated in Latin translation in Europe for about 200 years as the work of Constantinus Africanus until it was translated once more into Latin and thus the true author became known. In any case, the book by ʿAlī b. al-ʿAbbās was the only one with anatomical and surgical chapters to reach Salerno through Constantinus Africanus. That the origin of the well-known «Salernitanian Anatomy» was directly dependent on this book was already mentioned by Robert von Töply,[16] a contemporary of Sudhoff. It is revealing that more advanced illustrations with more precise descriptions are to be found in the Persian anatomy book and that here the number of figures increased from four to six. Of course, we do not wish to interpret this fact as the achievement of this particular author in whose book we encounter them, but rather as one of the many fruits brought forth by medicine in the Arabic-Islamic culture area to the end of the 8th/14th century. We only need to recall the significant progress in the knowledge of the anatomy of the eye that occurred between Ḥunain b. Isḥāq and Ibn al-Haiṯam, or Kamāladdīn al-Fārisī, as the case may be. To conclude, we may say a few words on Sudhoff's view that «the strict school of thought of Islam, to which all our Arabic medical authors belong, namely that of the Sunnis» had made it «impossible to … preserve the Alexandrian anatomical drawings and to hand them down to us by copying», a mentality from which he excludes «the more liberal school of thought of the Persian Shiites».

[15] v. H. Schipperges, *Arabische Medizin im lateinischen Mittelalter*, Berlin, Heidelberg, New York 1976, p. 39.

[16] *Studien zur Geschichte der Anatomie im Mittelalter*, Leipzig and Vienna 1898, p. 88; cf. Ynez Violé O'Neill, *The Fünfbilderserie reconsidered*, in: Bulletin of the History of Medicine (Baltimore) 43/1969/236-245; idem, *The Fünfbilderserieṣa bridge to the unknown*, in: Bulletin of the History of Medicine (Baltimore) 51/1977/538-549.

This judgment or reasoning with which he seems to credit the Shiite physicians in the six-hundred years under discussion here with a contribution which merely consisted in the preservation of the knowledge inherited from the Alexandrians is completely irrational and contradicts the present level of knowledge in the research[17] on the history of Arabic medicine: indeed, it ought to have occurred to Sudhoff that not an insignificant development took place between the extant anatomical drawings of the *Ḏaḫīra-i Ḫwārazmšāhī* (ca. 505/1110) and those of the *Tašrīḥ-i Manṣūrī* (ca. 800/1400).

[17] v. e.g., R. von Töply, op. cit., p. 63; H. Schipperges, Die Anatomie im arabischen Kulturkreis, in: Medizinische Monatsschrift (Stuttgart) 20/1966/67-73; idem, Arabische Medizin im lateinischen Mittelalter, op. cit., pp. 38-52, esp. p. 39 where he says: «For a systematic overview of Arabic surgery one must primarily consider anatomy, especially because it had been regarded since Antiquity as a propaedeutic to surgical procedure. In this field, we must dispense with many preconceived notions which assume that the dissection of human corpses polluted the Muslim, and that therefore tradition was only receptive and brought no benefit of any kind for scientific research. Moreover, it has been handed down again and again that the reproduction of the human figure was impossible for a Muslim to imagine.»
«Arab physicians like ʿAlī b. al-ʿAbbās or Avicenna include in their textbooks hundreds of anatomical monographs where not only the Alexandrian teachings of Hellenistic surgery but also numerous Old-Persian and Indian sources were absorbed. It is in the course of this literary assimilation that anatomy and surgery also found their secure position and continuous enrichment in the textbooks. Thus, Rhazes had already treated anatomy in 26 chapters in his 'Almansor'. ʿAlī b. al-ʿAbbās includes in the 9th book of his 'Liber Regius' no less than 110 chapters on anatomy and surgery, furthermore, the 10th book contains teachings on surgical medicine. Apart from a systematic anatomy, Avicenna's 'Canon medicinae' also refers to his own 'ʿilm al-ǧirāḥa' (knowledge of surgery). Ibn al-Haiṯam had an exact knowledge of the anatomy and physiology of the eye»; v. also Emilie Savage-Smith, Attitudes toward dissection in medieval Islam, in: The Journal of the History of Medicine and Allied Sciences 50/1995/67-110.

Fig. *1*: System of the Bones.

Fig. *2*: System of the Nerves.

Fig. *3*: System of the Muscles (without label.

Fig. *4*: System of the Veins.

Fig. *5*: System of the Arteries.

Fig*s*. *1–5*: Anatomical illustrations from *Ḏaḫīra-i Ḫwārazmšāhī* (ca. 505/1110), MS Oxford 1567, after Sudhoff.

Fig. *6*: System of the Bones.

Fig. *7*: System of the Muscles.

Fig*s*. *6–11*: Anatomical Illustrations from *Tašrīḥ-i Manṣūrī* (ca. 800/1400), MS Ayasofya (İstanbul) 3598.

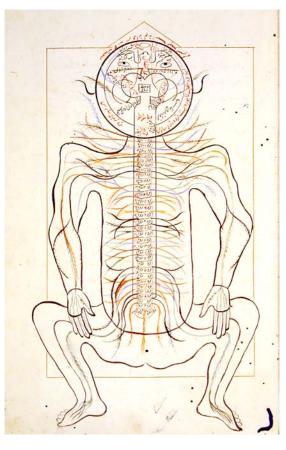



Fig. *8*: System of the Nerves.

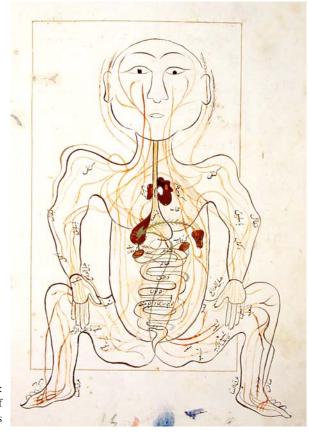



Fig. *9*: System of the Veins

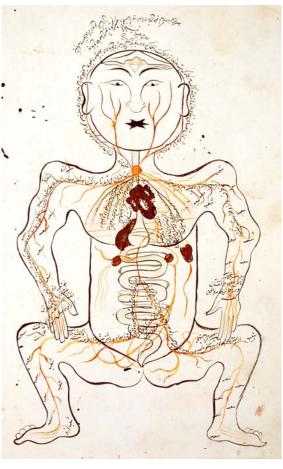



Fig. *10*: System of the Arteries

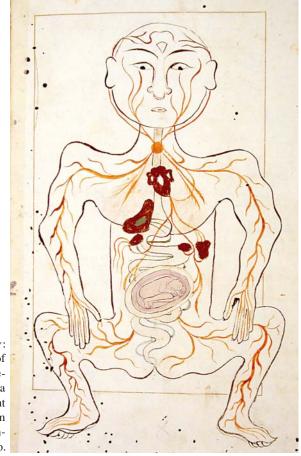



Fig. *11*: System of the Arteries of a pregnant woman with embryo.

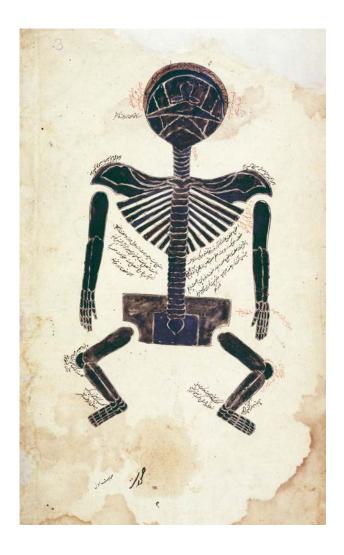
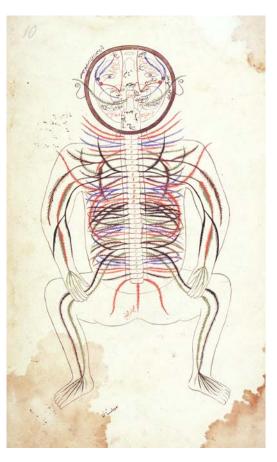



Fig. *14*: System of the Nerves, from *Tašrīḥ-i Manṣūrī*.

Fig. *15*: System of the Veins, from *Tašrīḥ-i Manṣūrī*.

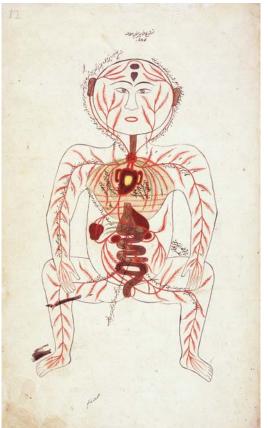
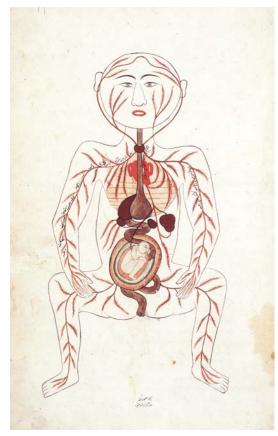
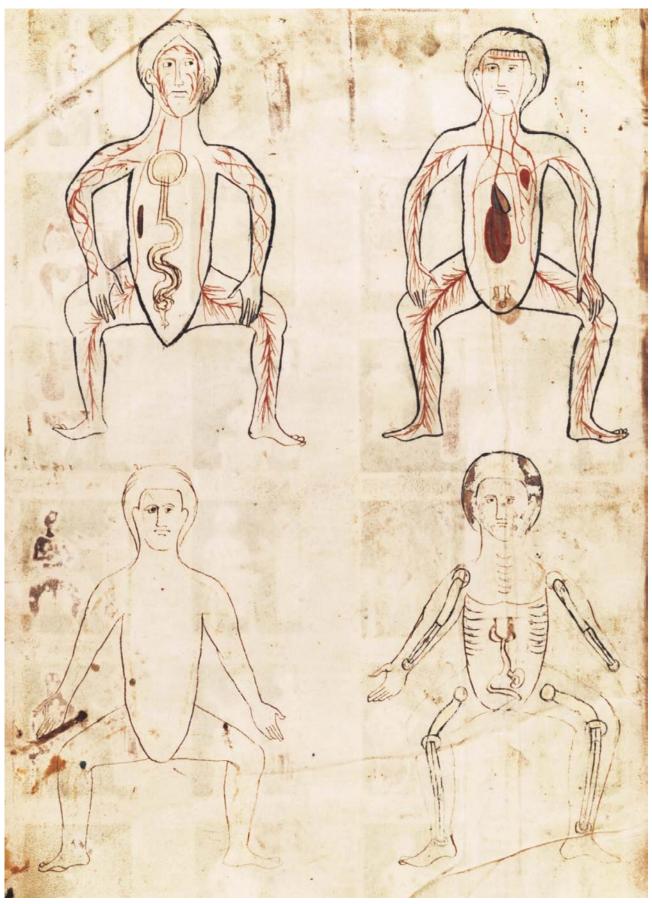



Fig. *16*: System of the Arteries, from *Tašrīḥ-i Manṣūrī*.

Fig. *17*: System of the Arteries of a pregnant woman with embryo, from *Tašrīḥ-i Manṣūrī*.

An incomplete series of Latin anatomical illustrations from MS Oxford, Cod. e. Museo 19.

3. Anatomical Illustrations of the Organ of Vision

One weak point of Arabic literature is that textual descriptions are not illustrated, as is desirable, with figures and sketches, with the exception of the fields of mathematics and astronomy. But even in these fields it happens not infrequently that the spaces for figures are left empty by the copyists, probably in anticipation that a specialist would be entrusted with this work. Those who are familiar with Arabic manuscripts are aware of the fact that in many cases autographs, if they are extant, contain illustrations whereas these are missing in the copies. During my studies of the history of Arab sciences and the question of their reception in the Occident, I gained the impression that many Arabic manuscripts with illustrations had the good fortune, as it were, to reach the Occident at an early stage so that their illustrations are preserved in the Latin translations. I am thinking here of the fine scenes of surgical treatment by Abu l-Qāsim az-Zahrāwī (see above, p. 5), which are missing in the Arabic manuscripts and which appear only in the Turkish version in an inferior quality.

In 1908 J. Hirschberg[1] lamented the state of manuscripts circulating without the illustrations of the originals: «The Arabs began … at an early date to embellish their textbooks of ophthalmology with anatomical illustrations of the organ of vision. Thus, according to the express mention of Ḫalīfa, the (for us lost) book 'of information about the diseases of the eye' by Ḥubaiš, the son of Ḥunain's sister, from Baghdad (from the 9th century of our era) was provided with an illustration of the eye. The textbook of ophthalmology by ʿAlī b. ʿĪsā from Baghdad from the beginning of the 11th century, which was a classic for the Arabs, did not contain any figures except a diagrammatic representation of the adhesion of the retina to the vitreous body. Unfortunately, this diagram is missing in all the five manuscripts which we could use. We make the same lament about the work by ʿAmmār of Mosul, which dates from about the same time: the text, although only in the Hebrew translation, speaks of figures, but shows only the empty spaces where those were meant to be entered.»

Julius Hirschberg, the great savant of Arabic-Islamic ophthalmology, did not yet know the three anatomical illustrations of the eye by Ḥunain b. Isḥāq (d. 260/873, see below, Figs. 1-3) which are preserved in the Cairo manuscript. Their discovery two years later was left to his younger colleague, Max Meyerhof. Hirschberg also did not yet know the Arabic original of the pictorial representation of the eye by Ibn al-Haiṯam whose Occidental successors can be traced up to the end of the 16th century. About the oldest Arabic drawing of the eye known to him, he says: «Fortunately we have this illustration of the optic nerve crossing together with that of the eye and the brain in a later Arabic text on ophthalmology, that by Ḫalīfa from Syria, from about 1266 our era, but only in the Jeni [Cami] manuscript of this work, not in the manuscript from Paris».[2] «First of all one must appreciate that the Arab ophthalmologists since Ḥunain had made real efforts to exploit the anatomy, the physiology and the pathology of the brain for their patients. Therefore we do not wish to criticize them for having dragged the optic nerve crossing unnaturally to the front in this imaginary stylized representation of the brain in order to be able to illustrate it at all; we also do that in our diagrams.»[3]

In connection with the anatomy of the eye and its nomenclature, Hirschberg says: «Not really from the Greeks, but rather from the Arabs, [**17**] i.e. from the medieval Latin translations of the same do we have the names for the membranes and the moistures of the eye which are in use today.»[4]

About the anatomy of the eye Hirschberg goes on to say: «Among the most important things which ar-Rāzī's [d. 313/925] *Kitāb al-Manṣūrī* period[5] hands down to us is the contraction of the pupil upon the incidence of light. The fact that the pupil of the healthy human eye contracts when there is brightness and dilates in darkness,—a fact which the first thinking human being ought to have noticed at each dusk in the eyes of his companion,—is, strangely enough, not to be found in the extant

[1] *Geschichte der Augenheilkunde*, 2nd and 3rd volumes: *Geschichte der Augenheilkunde im Mittelalter und in der Neuzeit*, Leipzig 1908, p. 150.

[2] ibid, p. 150.

[3] ibid, p. 152.

[4] J. Hirschberg, *Geschichte der Augenheilkunde*, op. cit., p. 154.

[5] v. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 3, pp. 281-283.

writings of any of the Greek authors, neither of the philosophers, nor of the physicians.»[6]

«Moreover, this is not just a casual remark by Rāzī, but the articulation of a fact that he recognized as important: he even wrote a special treatise on it under the title: 'Why pupils contract in light and dilate in darkness'.»[7] Here we may also mention the unusual chapter of a book on ophthalmology about «the differences of the eyes of animals compared to human eyes and the special characteristics of the latter». It is the sixth chapter of the *Kitāb al-ʿUmda* by Ṣadaqa b. Ibrāhīm aš-Šāḏilī from the second half of the 8th/14th century:[8] «This is rather a peculiar chapter, to a certain extent the seed of a comparative anatomy and physiology of the organ of vision: let us recall that even the detailed and classical textbooks of ophthalmology of the first two thirds of the 19th century, by J. Beer, Mackenzie, Artl, did not tackle this unwieldy topic; that only in our time did the most voluminous handbooks of ophthalmology, such as that by Graefe-Saemisch in the first edition II, 2, 1876, and our second edition which is not yet complete, after that also the Encyclopédie francaise d'ophtalmologie which is appearing just now, undertake to deal with this topic meticulously and scientifically. Thus we will not demand too much from our Šāḏilī.»[9]

Julius Hirschberg wrote his general history of ophthalmology at a time when Arabic studies and research into the history of the Arabic-Islamic natural sciences were still at a rather primitive level. Nevertheless, what Hirschberg brought out and published from Arabic-Persian literature on the subject of the anatomy of the eye retains its path-breaking significance for the subject even now. But if the modern historian of medicine misses an adequate impact of the insights gained by Hirschberg about Arabic medicine in general and the anatomy of the eye, in particular, in the subsequent historiography of the subject, the main reason probably lies in the fact that from the beginning a renowned and most prolific colleague like Karl Sudhoff continuously entertained a negative view towards the results presented by Hirschberg. It was not so much a well-founded scepticism towards the results arrived at by Hirschberg that motivated Sudhoff, but rather his fundamentally Eurocentric attitude towards the status of the Arabic-Islamic culture area in the history of science. According to his view, which is expressed again and again in his works, he not only denies any creative role in the history of science by the Arabic-Islamic culture area, but even denies it the role of a mediator between the Greeks and the Occident in the Middle Ages. He is of the opinion that the Occident got to know the works of the Greeks without the mediation of the Arabs and translated them directly into Latin, even if they had been translated into Arabic [**18**] and even if these translations might have reached the Occident.

The first scholar who opposed this attitude was, as far as I know, S. L. Polyak. In 1941 he wrote[10]: «The knowledge of the structure of the eye and of its function, possessed by western Europe during the Late Middle Ages, including the pictorial representation, manifestly was transplanted from the Near East, from the so-called 'Arabs', mostly by way of Spain, together with many other intellectual and practical pursuits, such as philosophy, medicine, alchemy, etc. It could not have been an indigenous product. This, if one realizes how completely annihilated was the Greek thought in the territories of the Christianized Teutonic barbarians and the degraded Latins of the West, is what could be expected. The belief that there was a tradition regarding the structure of the eye preserved in western Europe from classical Greek times, or possibly taken over directly from the cultural sphere of Alexandria, and even more so the claim that the early eye diagrams were a product of indigenous European efforts and thus independent from the Arabic Civilization and indirectly from the Greek Civilization (Sudhoff 1907, 1915; Bednarski 1935) seem, therefore, not to be well founded.»

In the ninth chapter of his book on *Arab diagrams of the eye and their influence in Europe upon the anatomy and physiology of the visual organs*,[11] Polyak offers the best discussion of the subject by a non-Arabist that we know of, aside from Hirsch-

[6] J. Hirschberg, *Geschichte der Augenheilkunde*, op. cit., p. 155.

[7] ibid, p. 156.

[8] ibid, pp. 84-85; C. Brockelmann, *Geschichte der arabischen Litteratur*, vol. 2, p. 137.

[9] J. Hirschberg, *Geschichte der Augenheilkunde*, op. cit., pp. 156-157.

[10] *The Retina. The anatomy and the histology of the retina in man, ape, and monkey, including the consideration of visual functions, the history of physiological optics, and the histological laboratory technique*, Chicago 1941, p. 128.

[11] ibid, p. 114 ff.

berg. He considers Ibn al-Haiṯam and his commentator Kamāladdīn al-Fārisī (ca. 700/1300) as important representatives of physiological optics and connects[12] the well-known works on optics written in Europe in the 13th century with the works of Ibn al-Haiṯam and Ibn Sīnā which had been available for more than a century in Latin translations. Witelo's *Perspectiva*, fundamentally an «analytical commentary on the work of Ibn al-Haiṯam and the first product of European endeavors in the field of optics,» strangely coincides with the commentary written in Persia by Kamāladdīn al-Fārisī, as far as the time and contents are concerned. The translation of Ibn al-Haiṯam's book and the appearance of Witelo's work mark, according to Polyak, the beginning of a long sequence of more or less important treatises on optics, among them the first and most popular works being those by Roger Bacon (ca. 1219-ca. 1292) and John Pecham (Peckham), the archbishop of Canterbury (ca. 1235-1292). Polyak considers all the European diagrams of the eye that were drawn for European works until the end of the 16th century, including those by Leonardo da Vinci, to be dependent on Arabic models.[13] Polyak, who was not an Arabist, was the first to publish and realize the importance of the Arabic diagrams of the eye by Ibn al-Haiṯam and Kamāladdīn al-Fārisī which are preserved in libraries in Istanbul. In the 1940s, following in the footsteps of the famous Eilhard Wiedemann, the Egyptian scholar Muṣṭafā Naẓīf[14] presented—to use the words of Matthias Schramm—«the optical achievements of Ibn al-Haiṯham in an exemplary fashion and extensively.» Twenty years later one more «exemplary» work on Ibn al-Haiṯam appeared. It is entitled *Ibn al-Haiṯhams Weg zur Physik*.[15] The scientist who enriched the scholarship on the history of Arabic-Islamic sciences with this book was Matthias Schramm himself. Here, I will not venture the difficult task of evaluating it in an adequate manner. However, it is not in this work, but in another, likewise excellent study that supplements this work, that Schramm pointed out a perspective which is completely novel for our topic. In this article, entitled *Zur Entwicklung der physiologischen Optik in der arabischen Literatur*,[16] he informs [**19**] us about Ibn al-Haiṯam's endeavors «to combine anatomical and optical reflections with one another».[17] From the point of view of physiological optics, the spherical form of the cornea was «no more a mere fact noticed by doctors of anatomy, but becomes a necessity: it alone guarantees the unbroken penetration of the rays which advance from all sides to the centre of the eye and to the centre of vision.» Thus Ibn al-Haiṯam gains «as a result of his physical contemplations … the first hypothesis of the construction of the eye, clearly defined by means of geometry».[18] Of great significance is also the fact that Schramm, by way of further developing physics and physiological optics as presented by Ibn al-Haiṯam, finds a work of high standard in the commentary by Kamāladdīn al-Fārisī, who was active three hundred years later. Of Schramm's statements, the one that refers to Kamāladdīn's theory on the image of the pupil[19] may be cited here because of its connection to our particular topic. Kamāladdīn states that the idea of Galen and his followers is untenable and that, through dissection of the eye of a slaughtered wether, he comes to the conclusion that during the formation of the image in the pupil the reflection takes place on the upper surface of the lens. Kamāladdīn's achievement is appreciated by Schramm[20] in the following words: «Through his deliberations and experiments Kamāl al-Dīn has been led to a result which was achieved afresh only in 1823 by Johannes Evangelista Purkynje. Kamāl al-Dīn was the first to detect definite proof for the reflection on the upper surface of the lens and gave reasons for it in the context of his theory in an excellent manner.»

[12] ibid, p. 126.
[13] ibid, p. 128.
[14] *Al-Ḥasan b. al-Haiṯam, buḥūṯuhū wa-kušūfuhu l-baṣarīya*, 2 vols., Cairo 1942-1943.
[15] Published in Wiesbaden, 1963.
[16] in: Sudhoffs Archiv für Geschichte der Medizin 43/1959/289-328.
[17] *Zur Entwicklung der physiologischen Optik*, op. cit., p. 295.
[18] ibid, p. 296.
[19] Kamāladdīn explains Galen's theory on the image of the pupil as follows: «Galen and those who follow him maintained: It is this (that is to say the layer which is like a spider's web) in which we see our image (*ṣūra*) if we look into the eye of somebody who is near us in the same way as we see in a mirror (*mir'āt*)» (*Tanqīḥ al-Manāẓir*, ed. Hyderabad 1347-48/1928-29, vol. 1, p. 65, translated by Schramm, *Zur Entwicklung der physiologischen Optik*, op. cit., p.308.)
[20] ibid, pp. 315-316.

The oldest preserved anatomical illustration of the eye is by Ḥunain b. Isḥāq (d. 259/873)[21]
[**20**] On the importance of this diagram of the eye, S. L. Polyak[22] wrote the following in 1941: «In his *Book of the Ten Treatises on the Eye* (*Kitāb al-ʿashr maḳālāt fī al-ʿain*) he gives a good description of the parts composing the eye, of the optic nerve and its connection with the brain, and also of the physiology of the visual system, besides the pathology and the treatment of eye diseases. In an Arabic manuscript of this book discovered by Meyerhof (1911), especially noteworthy are the diagrams of the eye. The best of these [v. ci-dessus, fig. 3] shows the inner structures of the eyeball in an imaginary horizontal cross-section inclosed in a frame representing the two lids as seen in a living person. Of the several circular layers, or coats, the most outward is the conjunctiva, to which the oculomotor nerve is attached on each side; the next is the sclera, together with the cornea; then the chorioid membrane, with the uvea (iris); and finally the retina, the innermost. This latter membrane, according to the text, is made up of two components—a hollow nerve, which apparently is the retina proper, and the blood vessels. The inner space of the eye is divided by a cross-partition into an anterior compartment, filled with the aqueous humor, and a posterior compartment, the vitreous. The crystalline lens is represented in the very center of the eyeball as a circular sphere, whereas in the text it is correctly described as flat. A thick semicircular line in front of the lens and continuous with the cross-partition represents the arachnoid membrane—in modern terminology the ‹anterior capsule› of the lens—together with the ciliary zonule and perhaps also the ciliary body. The most anterior portion of the outward tunic, facing upward and correctly showing the cornea with a smaller radius of curvature, is left unlabeled in the figure. The pupillary opening is represented by a small circle behind the cornea, inclosed in a cres-

Fig. *1*: The eye according to Ḥunain b. Isḥāq, MS Cairo, Dār al-Kutub, Taimūr 100, p. 319.

Fig. *2*: ibid., p. 346.

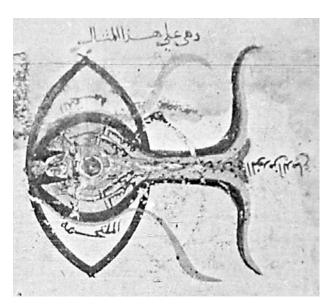



Fig. *3*: ibid., p. 318.

[21] *Tarkīb al-ʿain wa-ʿilaluhā wa-ʿilāǧuhā ʿalā raʾy Ibuqrāṭ wa-Ǧālīnʿs wa-hiya ʿašr maqālāt*, MS Cairo, Dār al-Kutub al-Qaumīya, collection Taimūr 100, pp. 314-318. Max Meyerhof (ed), *The Book of the Ten Treatises on the Eye Ascribed to Hunain ibn Ishâq (809-877 A. D.)*, Cairo 1928 (repr. Frankfurt 1996, Islamic Medicine vol. 22); M. Meyerhof and C. Prüfer, *Die Augenanatomie des Ḥunain b. Isḥâq. Nach einem illustrierten arabischen Manuskript herausgegeben*, in: Archiv für Geschichte der Medizin (Leipzig) 4/1910/163-191 (repr. Frankfurt 1996, Islamic Medicine vol. 23, pp. 45-73).
[22] *The Retina*, op. cit., pp. 106-107.

cent-shaped structure which represents the uvea, or the iris. The optic nerve is hollow. The two sheats enveloping the nerve, the dura and the pia, continue directly into the scleral and the chorioid tunic, respectively, while the optic nerve itself spreads out into the retina.»

«The obvious mistakes in this Arab diagram, which, like the text, is in all probability a copy or an adaptation from the Greek original of Galen's *On the Utility of the Parts of the Human Body* or from a similar treatise now lost, are at once apparent. First, the eyeball is too small in comparison with the palpebral fissure. Its walls are disproportionately thick, the anterior chamber too spacious, the posterior absent, and the vitreal cavity far too small. The two chief errors of the Greek anatomy —the location of the lens in the center of the eyeball and the channeling in the center of the optic nerve—have been faithfully copied by the Arabs. Yet, in spite of this, the figure gives a fair idea of the disposition of the minute structures of the eye and is unquestionably more correct than the confused geometrical diagrams which decorated numerous Latin manuscripts in Europe from the thirteenth to the fifteenth century and even later. Thus, for instance, the arrangement or sequence of the tunics of the eyeball and of the optic nerve is correct. Even the positions of the lens, with its suspension in the araneal tunic, and of the zonular ligament are nearer actuality than those represented in the above-mentioned geometrical schemes of the early European writers. Altogether, this venerable Arab diagram is more natural than the later, highly schematized, artificial Western figures. In one respect, viz., the curvature of the cornea, it is even more correct than the diagram of Vesalius, whose copy was published in Alhazen's and Vitello's joint edition (A.D. 1572).»

Some more, historically very important figurative representations of the anatomy of the eye follow, which are, moreover, suitable for depicting the paths of reception:

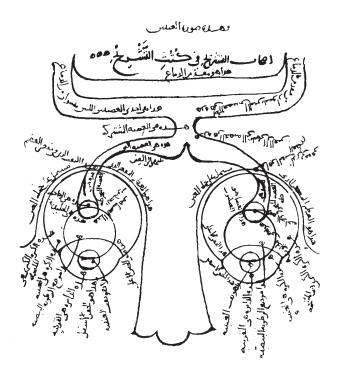



Fig. 4:
Illustration of the human organ of vision in the *Kitāb al-Manāẓir* by al-Ḥasan Ibn al-Haiṯam (ca. 432/1041), MS Istanbul, Süleymaniye Kütüphanesi, collection Fatih 3212, fol. 81b.[23]

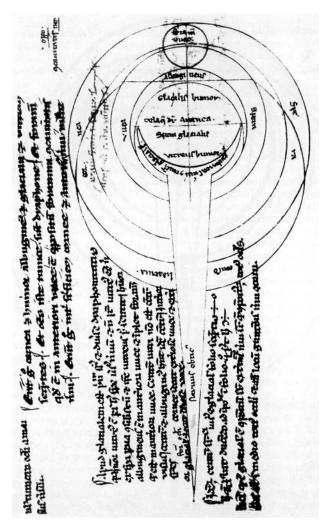
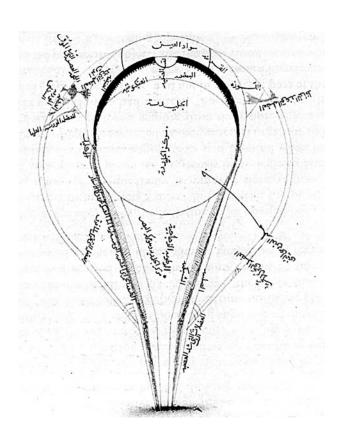



Fig. 5:
Longitudinal section of the human eye according to Ibn al-Haiṯam in the Latin translation of his optics, MS Edinburgh, Crawford Library of the Royal Observatory.[24]

[23] v. S. L. Polyak, *The Retina*, op. cit., fig. 8; David C. Lindberg, *Theories of Vision from al-Kindi to Kepler*, Chicago and London 1976, p. 68; A. I. Sabra, *The Optics of Ibn al-Haytham*, vol. 2, London 1989, p. 42, pl. 1.

[24] v. S. L. Polyak, *The Retina*, op. cit., fig. 13; A. I. Sabra, *The Optics of Ibn al-Haytham*, op. cit., p. 42, pl. 3.

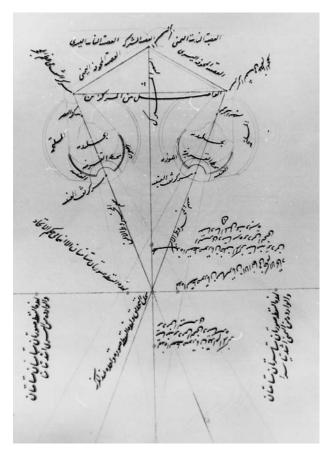



Fig. 6:
Longitudinal section of the human eye according to Kamāladdīn al-Fārisī (ca. 700/1300), *Tanqīḥ al-Manāẓir*, MS Istanbul, Topkapı Sarayı, Ahmet III, 3340, fol. 24b.[25]

Fig. 7:
One more sketch of the human organ of vision according to Kamāladdīn al-Fārisī (ca. 700/ 1300), from his book *al-Baṣā'ir fī 'ilm al-manāẓir*, MS Istanbul, Süleymaniye Kütüphanesi, collection Ayasofya 2451, fol. 42b.[26]

[25] v. S. L. Polyak, *The Retina*, op. cit., fig. 9; D. C. Lindberg, *Theories of Vision*, op. cit., p. 70; A. I. Sabra, *The Optics of Ibn al-Haytham*, op. cit., p. 42, pl. 2.

[26] Cf. S. L. Polyak, *The Retina*, op. cit., fig. 12.

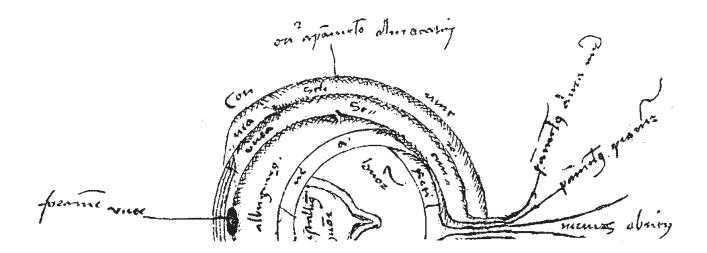



Fig. 8:
Latin rendering of an Arabic diagram which shows a longitudinal section through the eyeball.

The illustration became well known because it was included in the edition of the Latin translation of Ibn Sīnā's *Qānūn* of 1479.[27] K. Sudhoff[28] published the same diagram in 1907 after the Leipzig Codex 118 (folio 217) to provide proof «that even independently of the Arab tradition a longitudinal section through the eye must have been part of the inheritance throughout the Occidental Middle Ages.»

To this J. Hirschberg replied in a letter to Sudhoff: «It is true, the great textbooks of ophthalmology by Halifa and Salah ad-Din from Syria, which were provided with illustrations of the eye, were totally ignored by the Latin world of the European Middle Ages; but the latter got to know, among others, 'The Treatise on the Eye' of the Christian from Toledo, 'Salomo filius de Arit, Alcoati', from 1159; I was the first to show that it was written originally in the Arabic language and that it was derived entirely from Arabic sources. This work contained, in the first book, a figure of the eye of which the author is quite proud … The illustration in your manuscript is probably from this manuscript. Unfortunately, the figure was omitted in the only complete manuscript of Alcoati (No. 270 of the Amplon. Library at Erfurt), which was first published by our friend Pagel and which Pansier printed once again.»[29] Sudhoff took note of this statement by Hirschberg, at first, with some discomfiture[30] but, after another eight years, dismissed it: «I do not quite believe that this picture originated from Alcoati as Hirschberg assumed at that time (Archiv für Geschichte der Medizin, I, p. 316), particularly not after the Occident taught us several other graphic representations of the construction of the eye, and also because Alcoati positively detests transferring the cornea outside the conjunctiva. Alcoati had nothing of his own in his ophthalmology, least of all [**24**]

[27] Robert Töply, *Anatomia Ricardi Anglici* (c.a. 1242-1252), Vienna 1902, p. 39 (Additamenta), fig. 3.

[28] *Augenanatomiebilder im 15. und 16. Jahrhundert*, in: Studien zur Geschichte der Medizin, Heft 1, Leipzig 1907, pp. 19-26, esp. pp. 22-23.

[29] *Zum Leipziger Augendurchschnittsbilde aus dem Ende des 15. Jahrhunderts*, in: Archiv für Geschichte der Medizin (Leipzig) 1/1907/316.

[30] in: Archiv für Geschichte der Medizin 1/1907/316.

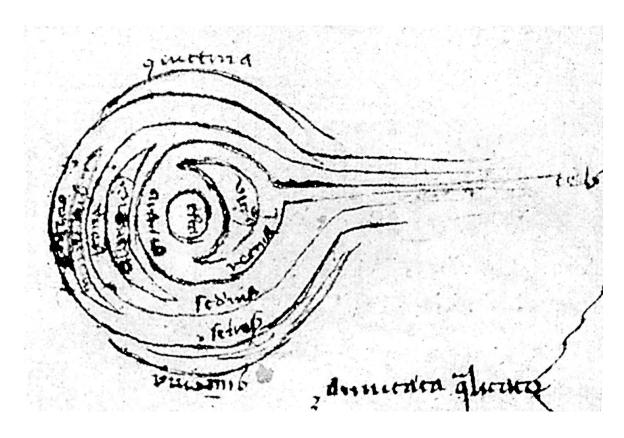



Fig. 9: Longitudinal section of the human eye after a Latin manuscript (Leipzig 1183, fol. 217) from the first half of the 15th century.

in anatomy. This has its origins entirely among the Greeks and came from them to the Arabs and into the Occident and to Salerno and other schools of physicians through all sorts of channels, and finally once more on the path of the Latin translations from the Arabic.»[31]
Then Sudhoff reproduces the illustration of the longitudinal section of the eye from the Leipzig manuscript 1183, fol. 217:
In 1941 S. L. Polyak[32] expressed his view on the two diagrams of the Leipzig Codex (15th cent.) and the incunabulum of the *Liber Canonis* by Ibn Sīnā (1479) and stated that they were either rough copies of the drawing by Kamāladdīn al-Fārisī or, more likely, of that drawings' common source in the book of optics by Ibn al-Haiṯam. In my view, we should rather suppose that both the diagrams (of Avicenna and of the Leipzig Codex) as well as the illustrations by «Alcoati» are connected to a stage of development that took place in the Arabic-Islamic culture area after Ibn al-Haiṯam but before 1159, a development which obviously also influenced Kamāladdīn al-Fārisī. It may also be pointed out that the 5th book of the Arabic original of «Salomo filius de Arit Alcoati» (written in 1159), has come to light,[33] the author of which could perhaps have been called Sulaimān b. Ḥāriṯ al-Qūṭī.

[31] *Weitere Beiträge zur Geschichte der Anatomie im Mittelalter*, in: Archiv für Geschichte der Medizin 8/1914-15/1-21, esp. pp. 9-10.
[32] *The Retina*, op. cit., p. 128.
[33] Escurial 894 (44a-76a), v. J. Hirschberg, *Geschichte der Augenheilkunde*, Leipzig 1908, pp. 70-71. Editions, studies and translations of the book were published in Islamic Medicine vol. 56, Frankfurt 1996.

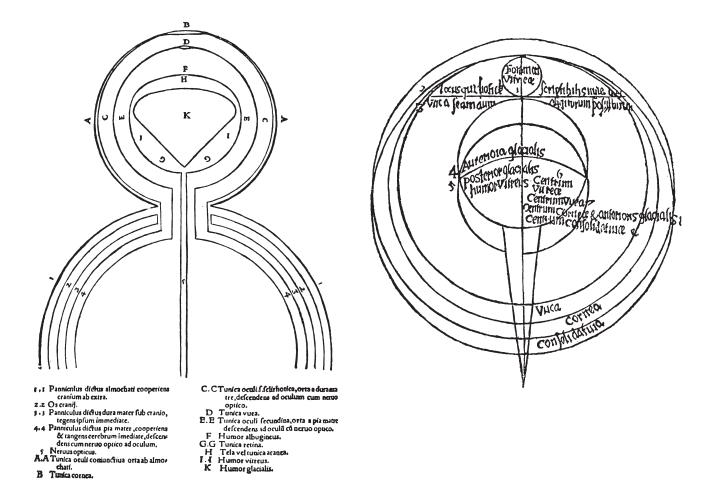
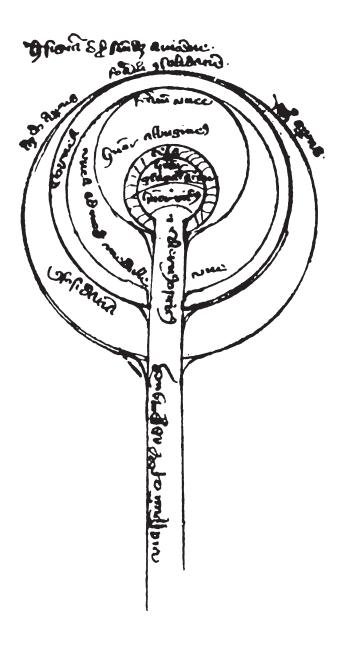



Fig. 10: Diagram of the membranes of the skull and the brain and of the eyeball with its membranes from a print of the *Liber Canonis* by Avicenna (Ibn Sīnā) from the year 1544 (fol. 416).[34] It is still an open question as to whether the diagram is really by Ibn Sīnā or not.

Fig. 11: Longitudinal section of the human eye after Roger Bacon (ca. 1219-ca. 1292), from the *Perspectiua Rogerii Bacconis*, Frankfurt 1614, p. 27.[35]

[34] K. Sudhoff, *Weitere Beiträge zur Geschichte der Anatomie im Mittelalter*, in: Archiv für Geschichte der Medizin (Leipzig) 8/1914-15/1-21, esp. pp. 19-20.

[35] v. Adam Bednarski, *Die anatomischen Augenbilder in den Handschriften des Roger Bacon, Johann Peckham and Witelo*, in: Sudhoffs Archiv für Geschichte der Medizin 24/1931/60-78, esp. p. 62.

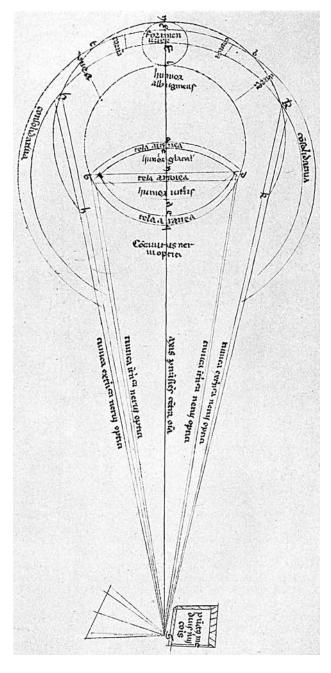
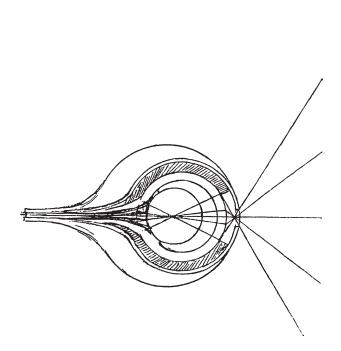



Fig. 12: Longitudinal section of the human eye after John Pecham (Peckham, or similar other forms), the archbishop of Canterbury (ca. 1235-1292), in the manuscript F. IV. 30 (fol. 128b) of the Basel university library.[36]

Fig. 13: Illustration of the human organ of vision after that in Witelo's (ca. 1230-ca. 1279) *Perspectiva*, Oxford, Bodleian Library, MS Ashmole 424.[37]

[36] v. A. Bednarski, op. cit., p. 65; cf. S. L. Polyak, *The Retina*, op. cit., fig. 15.

[37] v. S. L. Polyak, *The Retina*, op. cit., fig. 16.

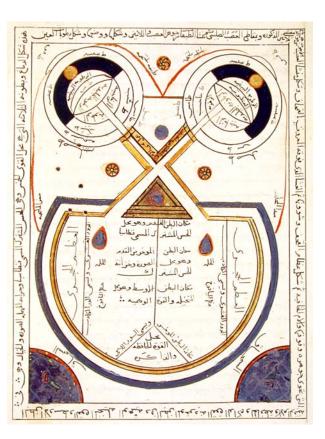



Fig. 14: Illustration of human vision after Leonardo da Vinci (1452 -1519), from *Codice Atlantico*, vol. 3, fol. 628.[38]

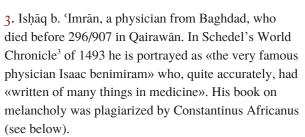
Fig. 15: Crossing of the optic nerves from the book on ophthalmology by Ḫalīfa.[39]

Julius Hirschberg, who copied and published this illustration[40] (see above, p. 5), after pointing out its deficiencies and merits,[41] evaluates it in the following manner: «In any case we see in this venerable picture, which probably goes back to models at least from the time around 1000 A.D., a cautious attempt to represent what D. W. Soemmerring[42] insightfully arranged in his classic illustration in 1827.»

[38] v. S. L. Polyak, *The Retina*, op. cit., fig. 24; K. Sudhoff, *Augenanatomiebilder im 15. und 16. Jahrhundert*, op. cit., p. 26.

[39] MS Istanbul, Süleymaniye Kütüphanesi, collection Yeni Cami No. 924, fol. 12a.
[40] *ʿAmmār b. ʿAlī* ..., op. cit., p. 34.
[41] ibid, p. 164.
[42] *De oculorum hominis animaliumque sectione horizontali commentatio*, Göttingen 1818, table 1; on this, v. S. Ry Andersen, Ole Munk and H. D. Schepelern, *An Extract of Detmar Wilhelm Soemmerring's thesis: A Comment on the horizontal section of eyes in man and animals*, Copenhagen 1971.

4.
Portraits of Famous Physicians

1. Dioscorides (2nd half of the 1st cent. B.C.), in a posture of teaching, from the Arabic translation of his Materia Medica, MS Istanbul, Topkapı Sarayı, collection Ahmet III, 2127 of 626/1229 (fol. 1b).[1]

2. Dioscorides and a pupil, from the Arabic translation of his Materia Medica, MS Istanbul, Topkapı Sarayı, collection Ahmet III, 2127 of 626/1229 (fol. 2b).[2]

[1] v. Richard Ettinghausen, *Arabische Malerei*, Geneva 1962, p. 69.

[2] v. Richard Ettinghausen, *Arabische Malerei*, op. cit., p. 71.

3. Isḥāq b. ʿImrān, a physician from Baghdad, who died before 296/907 in Qairawān. In Schedel's World Chronicle[3] of 1493 he is portrayed as «the very famous physician Isaac benimiram» who, quite accurately, had «written of many things in medicine». His book on melancholy was plagiarized by Constantinus Africanus (see below).

4. An occidental portrait of Abū Bakr ar-Rāzī, Latinized Rhazes (physician, chemist and philosopher, d. 313/925), from the translation of his medical encyclopedia *al-Ḥāwī* (*Liber Continens*), printed frequently since 1486.[4]

[3] Hartmann Schedel, *Buch der Cronicken*, Nuremberg 1493 (repr. under the title *Weltchronik*, ed. Stephan Füssel, Cologne, London etc. n.d.), folio 192 b.
It is remarkable that, on the one hand, this physician who is not well known in the West is at least mentioned by Schedel—who is otherwise not exactly receptive towards Islamic culture—, on the other hand, the same woodcut said to be his likeness, a few pages later is supposed to represent «Avicenna, a physician, the most famous of all doctors of medicine.» All the same, a detailed passage with praise for the latter is included there (folio 202) .

[4] v. Daniel M. Albert and Diane D. Edwards (eds.), *The History of Ophthalmology*, Cambridge MA 1996, p. 30.

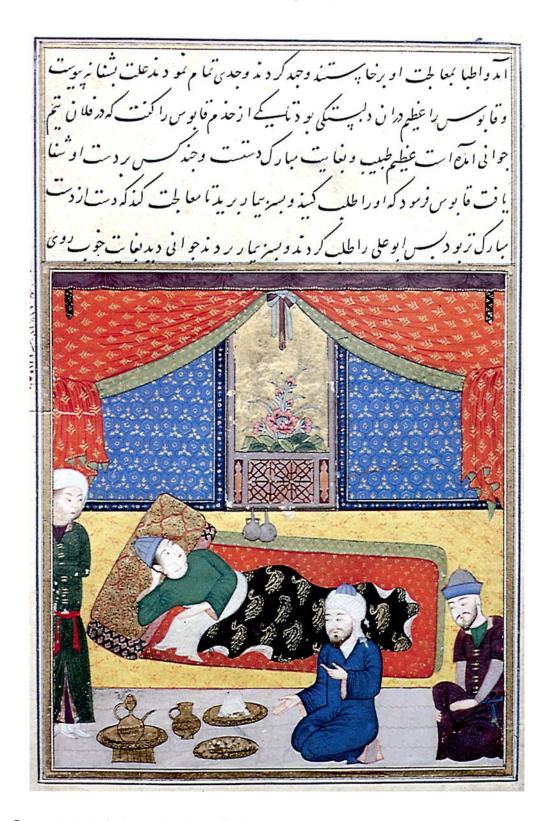
5. Abū Bakr ar-Rāzī (Rhazes), after the portrayal in the Latin translation of his Ḥāwī in a manuscript of 1506.[5]

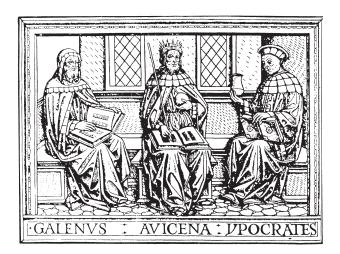
6. An occidental picture, dating probably from the 15th century, of Abu l-Qāsim az-Zahrāwī, Latinized Albucasis (4th/10th cent.). The chapter on surgery, which will be cited often below, of his *Kitāb at-Taṣrīf* had a deep influence on occidental medicine. The original of the picture is in the Biblioteca Apostolica Vaticana, MS Chigi F. VII. 158 (fol. 49a).[6]

[5] v. *Europa und der Orient 800-1900* (exhibition catalogue), ed. G. Sievernich and H. Budde, Berlin 1989, p. 128.

[6] v. Sami Kh. Hamarneh and Glenn Sonnedecker, *A Pharmaceutical View of Abulcasis al-Zahrāwī in Moorish Spain*, Leiden 1963, illustration after p. 22.

7. One more occidental picture of Abu l-Qāsim az-Zahrāwī (on the left in the picture). It is on the title page of *Liber Theoricae nec non Practicae*, the Latin translation of the first and second chapter of his *at-Taṣrīf*, in the edition by Sigismund Grimm, Augsburg 1519.[7]

8. An occidental portrait of Abū ʿAlī Ibn Sīnā (d. 428/1037), known in the Latin West as Avicenna. The portrait adorns the initial letter of the introduction to the Latin translation of his *al-Qānūn fi ṭ-ṭibb* (*Canon Medicinae*), Venice 1483.[8]

9. Ibn Sīnā (Avicenna), together with Hippocrates (d. 377 B.C.), Galen (2nd cent. A.D.) and Aetius (6th cent. A.D.), on the title page of the Latin translation of his *Qānūn* in the edition Venice 1608.[9]

[7] v. S. Hamarneh, G. Sonnedecker, op. cit., ill. after p. 28.
[8] v. *Europa und der Orient 800-1900*, op. cit., p. 131.
[9] v. H. Schipperges, *Arabische Medizin im lateinischen Mittelalter*, op. cit., p. 35.

10. Ibn Sīnā at the bed of a lovesick nephew of Qābūs b. Wušmgīr, a ruler from the Ziyāride dynasty in northern Persia, at whose court Ibn Sīnā spent some time. The illustration is to be found in the *Čahār maqāla* by Niẓāmī-i ʿArūḍī, in a manuscript dating from 835/1431 of the Museum for Turkish and Islamic Art in Istanbul[10].

[10] v. Arslan Terzioğlu, *Yeni araştırmalar ışığında büyük türk–islâm bilim adamı Ibn Sina (Avicenna) ve tababet*, İstanbul 1998, p. 97; *À l'ombre d'Avicenne. La médecine au temps des califes* (exhibition catalogue), Paris: IMA, 1996, p. 114.

11. Galen, Ibn Sīnā and Hippocrates as colleagues on the title page of the Latin translation of the *Qānūn* in the edition Pavia 1515.[11].

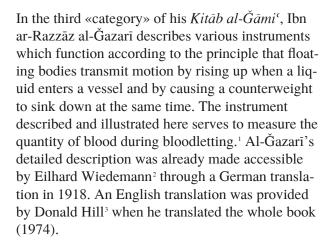
13. A scholar in Muslim dress, probably representing Ibn Sīnā (Avicenna), shown in the middle, standing out, quite literally, among the «three philosophers» in the thus entitled painting by the Italian painter Giorgione (d. 1510). The original of the picture hangs in the Kunsthistorisches Museum Vienna[13].

12. Reading the Latin translation of Ibn Sīnā's *Qānūn*, from an illuminated parchment manuscript of the *Canon Medicinae* from the 15th century[12].

14. Haly Abbas (ʿAlī b. al-ʿAbbās al-Maǧūsī, d. ca. 400/1000) and Constantinus Africanus (d. 1087), together with Ysaac (Isḥāq b. Sulaimān al-Isrāʾīlī, d. 320/932), the author of *Kitāb al-Aġḏiya*. The illustration is taken from the title page of the Latin translation of his book, published in *Omnia opera ysaac*, Lyon 1515[14].

[11] v. A. Terzioğlu, *Yeni araştırmalar ışığında …*, p. 84.
[12] v. *Europa und der Orient 800–1900*, p. 103.
[13] v. A. Terzioğlu, *Yeni araştırmalar ışığında …*, p. 85.
[14] v. H. Schipperges, *Arabische Medizin im lateinischen Mittelalter*, p. 170.

15. «Auenzoar a physician», illustration and reference in Schedel's World Chronicle (1493). The reference is to ʿAbdalmalik Ibn Zuhr (d. 557/1162), who came to be known in the Occident as Avenzoar. Schedel also mentions his «Book of Medicine Theysir» that is *at-Taisīr fi l-mudāwāt wa-t-tadbīr*, which was translated into Latin[15].

16. «Auerrois a physician and lover of wisdom», illustration and reference from Schedel's World Chronicle (1493). It is the versatile philosopher Muḥammad b. Aḥmad b. Muḥammad Ibn Rušd (d. 595/1198), Averroes of the Latins. Schedel has some historical and geographical knowledge about his life and achievements[16].

[15] Hartmann Schedel, *Buch der Cronicken*, fol. 202 a.

[16] Ibid., fol. 202 a.

Two Instruments

for Measuring the Quantity

of Blood after Bloodletting

In the third «category» of his *Kitāb al-Ǧāmiʿ*, Ibn ar-Razzāz al-Ǧazarī describes various instruments which function according to the principle that floating bodies transmit motion by rising up when a liquid enters a vessel and by causing a counterweight to sink down at the same time. The instrument described and illustrated here serves to measure the quantity of blood during bloodletting.[1] Al-Ǧazarī's detailed description was already made accessible by Eilhard Wiedemann[2] through a German translation in 1918. An English translation was provided by Donald Hill[3] when he translated the whole book (1974).

1. Our Model (on the left):
Figure: Pear tree wood, lacquered.
Column and measuring vessel of perspex, partly lacquered.
Base plate of brass, gilded.
Round plate with engraving (a scale of 120 units) and brass bowl, gilded.
Float and counterweight, inside brass.
Wooden table mahogany veneer (35 × 49 cm).
Aluminium feet and perspex cover.

2. Our Model (on the right):
Figures: Pear tree wood, lacquered.
Column and measuring vessel of perspex, partly lacquered.
Float and counterweight, inside brass.
Total height: 53 cm.
(Inventory No. H 3.02)

[1] Facs. editions, Ankara 1990, pp. 244-248; Frankfurt 2002, pp. 384–390.

[2] E. Wiedemann and Fritz Hauser: *Über Schalen, die beim Aderlaß verwendet werden, und Waschgefäße nach Gazarî*, in: Archiv für Geschichte der Medizin (Leipzig) 11/1918/22–43, esp. pp. 32–35 (reprint in: E. Wiedemann, *Gesammelte Schriften*, vol. 3, pp. 1607–1628, esp. pp. 1617–1620).

[3] *The Book of Knowledge of Ingenious Mechanical Devices*, pp. 137–139.

Cauter
in the form of a fingernail
(*mikwāt mismārīya*)

From the *Kitāb at-Taṣrīf* of az-Zahrāwī[1]
(4th/10th cent.).

Our model:
Brass and stainless steel.
Length: 118 mm.
(Inventory No. H 1.01)

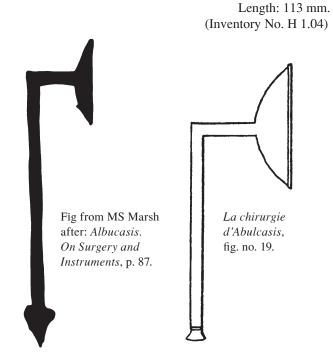
Kitāb at-Taṣrīf, facs. ed., vol. 2, p. 464.

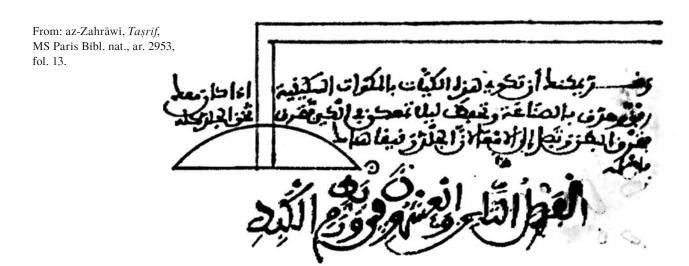
Another
Cauter
in the form of a fingernail
(*mikwāt mismārīya*)

From the *Kitāb at-Taṣrīf* of az-Zahrāwī[2]
(4th/10th cent.).

Our model:
Brass and stainless steel.
Length: 129 mm.
(Inventory No. H 1.02).

From: Leclerc, *La Chirurgie d'Abulcasis,* fig. 4, after Gurlt, *Geschichte der Chirurgie.*

[1] Abu l-Qāsim az-Zahrāwī, Ḫalaf b. ʿAbbās, *at-Taṣrīf li-man ʿağiza ʿan at-taʾlīf*, facs. ed., Frankfurt 1986, vol. 2, p. 464; *La chirurgie d'Abulcasis… traduite* par Lucien Leclerc, Paris 1861 (reprint Frankfurt 1996, Islamic Medicine, vol. 36), p. 15, fig. no. 3; *Albucasis. On Surgery and Instruments. A Definitive Edition of the Arabic Text with English Translation and Commentary* by M.S. Spink and G.L. Lewis, London 1973, p. 25.

[2] Az-Zahrāwī, op. cit., vol. 2, p. 470; *La chirurgie d'Abulcasis*, p. 15, fig. no. 4; *Albucasis. On Surgery and Instruments*, p. 97.

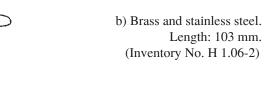
Our model:
Brass and stainless steel.
Length: 113 mm.
(Inventory No. H 1.04)

Instrument for cauterisation
in the case of ‹cold liver›
(*mikwāt fī kaiy al-kabid al-bārida*)

from the *Kitāb at-Taṣrīf* by az-Zahrāwī.
Our model is based on the text and on the illustrations in one of the Paris manuscripts[3] (v. fig. below) and in the manuscript Oxford, Bodleiana, Marsh[4]. The manuscripts also show the form of the track of the burn, from which it is apparent that the instrument ended in a flat tip, shaped like a lancet.

Fig from MS Marsh after: *Albucasis. On Surgery and Instruments*, p. 87.

La chirurgie d'Abulcasis, fig. no. 19.

From: az-Zahrāwī, *Taṣrīf*, MS Paris Bibl. nat., ar. 2953, fol. 13.

[3] *La chirurgie d'Abulcasis*, op. cit., pp. 32-33, fig. no. 19.
[4] *Albucasis. On Surgery and Instruments*, op. cit., p. 87.

Cauter
for the treatment of the feet and the thighs
(*mikwāt fī kaiy al-qadamain wa-s-sāqain*)

Our two models (a, b) reproduce the illustrations in the manuscripts from Paris[5] Istanbul[6] and Oxford[7] of the *Taṣrīf* by az-Zahrāwī (4th/10th cent.).

Our models:
a) Brass and stainless steel.
Length: 121 mm.
(Inventory No. H 1.06-1)

At-Taṣrīf, facsimile ed., vol. 2, p. 470.

b) Brass and stainless steel.
Length: 103 mm.
(Inventory No. H 1.06-2)

From: L. Leclerc, *La chirurgie d'Abulcasis*, fig. 21; after Gurlt, *Geschichte der Chirurgie*.

MS Marsh, from: *Albucasis. On Surgery and Instruments*, p. 97.

[5] L. Leclerc, *La chirurgie d'Abulcasis*, pp. 36–37, fig. no. 21; E. Gurlt, *Geschichte der Chirurgie,* pl. IV, no. 21.
[6] *At-Taṣrīf*, facsimile ed., vol. 2, p. 470.
[7] *Albucasis. On Surgery and Instruments*, p. 97.

TREATMENTS OF THE HEAD AND THE FACE

‹olive› Cauter

(*mikwāt zaitūnīya*)
for a single cauterisation of the head
(*fī kaiy ar-ra'ʾs kaiyan wāḥidan*)

Our model:
Brass and stainless steel.
Length: 127 mm.
(Inventory No. H 1.03)

Kitāb at-Taṣrīf,
facsimile ed., vol. 2,

from the *Kitāb at-Taṣrīf* by az-Zahrāwī[1] (4th/10th cent.). Probably Leclerc (v. fig. below) allowed himself to be misled by the name of this important instrument and regarded the handle in the manuscripts available to him as the tip of the cauter. At the time of az-Zahrāwī, the real cauter (v. fig. on the right) probably had no likeness (any more) with an olive seed, which might have been decisive for the naming of the instrument that is known from Antiquity.

From: *Kitāb at-Taṣrīf*, MS İstanbul, Ahmet III 1990 (8th/14th cent.), fol. 7b.

Leclerc, *La Chirurgie d'Abulcasis*, fig. 1 & 2; after Gurlt, *Geschichte der Chirurgie*.

Our model:
Brass and stainless steel.
Length: 120 mm.
(Inventory No. H 1.07

Another

Instrument for cauterisation

on the head, at the temples
and on the back of the skull

Constructed after an illustration from the *Kitāb at-Taṣrīf* by az-Zahrāwī as copied by L. Leclerc[2].

Albucasis. On Surgery and Instruments, p. 17 (MS Oxford, Huntington 156).

[1] Az-Zahrāwī, op. cit., vol. 2, p. 463; *La chirurgie d'Abulcasis*, p. 12, fig. no. 1; cf. *Albucasis. On Surgery and Instruments*, p. 17.

Cauter
to be used in the case of paralysis of the face
(*mikwāt al-laqwa*)

Our model is based on a sketch drawn by L. Leclerc after an illustration in one of the Paris manuscripts of the *Kitāb at-Taṣrīf* by az-Zahrāwī (4th/10th cent.).[3]

Our model:
Brass and stainless steel.
Length: 120 mm.
(Inventory No. H 1.08)

L. Leclerc,
La chirurgie d'Abulcasis,
fig. 6a.

Another
Cauter
to be used in the case of paralysis of the face
(*mikwāt al-laqwa*)

Our model reproduces an alternative sketch drawn by L. Leclerc after an illustration from one of the Paris manuscripts of the *Kitāb at-Taṣrīf* by az-Zahrāwī (4th/10th cent.)[4].

Our model:
Brass and stainless steel.
Length: 120 mm.
(Inventory No. H 1.09)

L. Leclerc,
La chirurgie d'Abulcasis,
fig. 6.

[3] *La chirurgie d'Abulcasis*, op. cit., pp. 17-18, fig. 6 bis; cf. MS İstanbul, Veliyeddin 2491, fol. 109a–b.
[4] *La chirurgie d'Abulcasis*, op. cit., p. 17–18, fig. 6.

az-Zahrāwī, *Taṣrīf*, MS Paris Bibl. nat., ar. 2953, fol. 10b.

Small

Cauter in the shape of a scalpel

for the treatment of fissures on the lips

(*mikwāt ṣaġīra sikkīnīya li-kaiy šiqāq aš-šafa*)

Our model was made after the illustration in a Paris manuscript of the *Taṣrīf* by az-Zahrāwī (4th/10th cent.) and its copy drawn by L. Leclerc[5].

Our model:
Brass and stainless steel.
Length: 120 mm.
(Inventory No. H 1.10)

L. Leclerc, *La chirurgie d'Abulcasis*, fig. 13.

[5] *La chirurgie d'Abulcasis*, p. 27, fig. 13; E. Gurlt, *Geschichte der Chirurgie*, pl. IV, no. 13; cf. *Albucasis. On Surgery and Instruments*, p. 61.

TREATMENT OF THE EYES

Cauter

for the treatment of fistulas in the tear gland

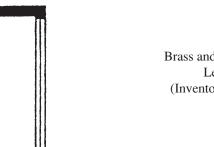
(*fī kaiy an-nāṣūr allaḏī fī maʾaq al-ʿain*)

La chirurgie d'Abulcasis, fig 11.

Our model was prepared according to the sketch drawn by L. Leclerc[1] after the illustrations in the Paris manuscripts of the *Taṣrīf* by az-Zahrāwī (4th/10th cent.).

Our model:
Brass and stainless steel.
Length: 135 mm.
(Inventory No. H 2.01

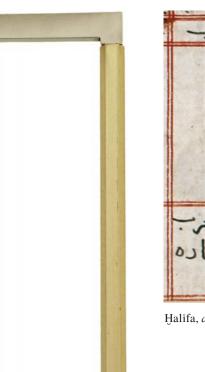
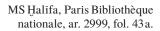
A second version of the same instrument was prepared after the illustration in manuscript Veliyeddin[1] (Istanbul).

Our model:
Brass and stainless steel.
Length: 132 mm.
(Inventory No. H 2.02)

az-Zahrāwī, *Taṣrīf*, MS Veliyeddin no. 2491, fol. 112a.

az-Zahrāwī, *Taṣrīf*, MS Paris Bibl. nat., ar. 2953, fol. 10b.

[1] *La chirurgie d'Abulcasis*, op. cit., pp. 25–26, fig. no. 11.
[2] *At-Taṣrīf*, MS Veliyeddin no. 2491, fol. 112a, cf. *Albucasis. On Surgery and Instruments*, p. 57.

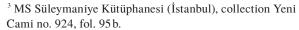
Cauter for the tear gland fistula

(*mikwāt al-ġarab*)

»This is used to cauterise the tear gland fistula after its rupture» (Ḫalīfa al-Ḥalabī).
Our model was made after the illustration in the *al-Kāfī fi l-kuḥl*[3] by Ḫalīfa b. Abi l-Maḥāsin al-Ḥalabī[4] (written before 674/1275) and after the sketch by J. Hirschberg.[5]

Drawing by Hirschberg, p. 167, No. 21.

Our model:
Brass and stainless steel.
Length: 113 mm.
(Inventory No. H 2.04)

يكوى العرب
يكوى به العرب
بعد انفجاره

Ḫalīfa, *al-Kāfī*, MS Yeni Cami no. 924, fol. 95 b.

MS Ḫalīfa, Paris Bibliothèque nationale, ar. 2999, fol. 43 a.

Cleaner

for the tear gland fistula

(*miḥsaf al-ġarab*)

«This is used to clean the entire corner of the eye – for those who do not like cauterisation near the fistula» (Ḫalīfa). (Ḫalīfa).
Our model was made after the illustration in the Paris[6] manuscript of the *Kitāb al-Kāfī fi l-kuḥl* by Ḫalīfa al-Ḥalabī[7].

Our model:
Stainless steel and wood.
Length: 122 mm.
(Inventory No. H 2.05)

[3] MS Süleymaniye Kütüphanesi (İstanbul), collection Yeni Cami no. 924, fol. 95 b.
[4] v. C. Brockelmann, *Geschichte der arabischen Litteratur*, suppl. vol. 1, p. 899.
[5] *ʿAmmār b. ʿAlī al-Mauṣilī: Das Buch der Auswahl von den Augenkrankheiten. Ḫalīfa al-Ḥalabī: Das Buch vom Genügenden in der Augenheilkunde. Ṣalāḥ ad-Dīn: Licht der Augen. Aus arabischen Handschriften übersetzt und erläutert von* J. Hirschberg, J. Lippert and E. Mittwoch, Leipzig 1905 (repr. in: Islamic Medicine, vol. 45), p. 167, fig. no. 21, v. also p. 169.

[6] Bibliothèque nationale, ar. 2999, fol. 43 a.
[7] v. *ʿAmmār b. ʿAlī*…, p. 167, fig. no. 23, v. also p. 169.

Cataract needle

(*miqdaḥ*)

Constructed after the illustration in the *Taṣrīf* by az-Zahrāwī (4th/10th cent.)[8].

Our model:
Brass and stainless steel.
Length: 122 mm.
(Inventory No. H 2.13)

az-Zahrāwī, *at-Taṣrīf*, facsimile ed., vol. 2, p. 488.

Cataract needle

(*barīd*)

Our model reproduces the sketch drawn by L. Leclerc[9] after an illustration in the Paris manuscripts of az-Zahrāwī's book (4th/10th cent.).

Our model:
Brass and stainless steel.
Length: 130 mm.
(Inventory No. H 2.12)

Leclerc, *La chirurgie d'Abulcasis*, fig. no. 50.

[8] *At-Taṣrīf*, facsimile ed., vol. 2, p. 488; Leclerc, *La chirurgie d'Abulcasis*, p. 92–93, fig. no. 51 et 52.
[9] *La chirurgie d'Abulcasis*, p. 92, fig. no. 50; cf. *ʿAmmār b. ʿAlī…*, p. 173.

Spear

(*ḥarba*)

«This one cleaves the sebaceous cyst and reaches under it and cuts it off. It is made dispensable by the myrtle leaf (*āsa*, see below),» says Ḫalīfa in his *al-Kāfī*[10] (written before 674/1275). Our model was made after the illustration in Ḫalīfa's *al-Kāfī*.

Our model:
Brass and stainless steel.
Length: 121 mm.
(Inventory No. H 2.17)

Ḫalīfa, *al-Kāfī*, MS Yeni Cami no. 924, fol. 95b.

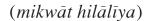
Rose leaf

(*warda*)

«For cutting off the mulberry (tumour) of the lid, also used for cutting off the sebaceous cyst and for some other operations» (Ḫalīfa).
Our model was prepared after the illustrations in the two manuscripts of the *Kitāb al-Kāfī* by Ḫalīfa (written before 674/1275) and the sketch by J. Hirschberg.[11]

Our model:
Brass and stainless steel.
Length: 111 mm.
(Inventory No. H 2.18)
)

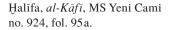
Ḫalīfa, *al-Kāfī*, MS Yeni Cami no. 924, fol. 95b.

[10] MS Paris Bibliothèque nationale, ar. 2999, fol. 42b; İstanbul, Süleymaniye, collection Yeni Cami 924, fol. 95b; *ʿAmmār b. ʿAlī*, op. cit., p. 166, fig. no. 9, là-dessus p. 166.
[11] MS Paris Bibliothèque nationale, ar. 2999, fol. 42b; MS İstanbul, Süleymaniye, collection Yeni Cami 924, fol. 95b; *ʿAmmār b. ʿAlī*, op. cit., pp. 165–168 passim, fig. no. 7.

Our model:
Brass and stainless steel.
Length: 126 mm.
(Inventory No. H 2.07)

Crescent-shaped Cauter

(*mikwāt hilālīya*)

az-Zahrāwī, *Kitāb at-Taṣrīf*, facsimile ed., vol. 2, p. 466.

It is used when the eyelids become limp. Our model reproduces the illustration in the Istanbul manuscript (Beşirağa) of az-Zahrāwī's book[12] (4th/10th cent.), chapter 15.

Scissors (*miqaṣṣ*) for the eyelids

A pair of scissors «with broad blades. Their length is set according to how much is cut off from the eyelid» (Ḫalīfa).
Our model is based on the illustration in the Kitāb al-Kāfī by Ḫalīfa al-Ḥalabī (written before 674/1275) in the manuscript Yeni Cami[13] and the sketch by J. Hirschberg[14].

Notre modèle:

Ḫalīfa, *al-Kāfī*, MS Yeni Cami no. 924, fol. 95a.

Ḫalīfa, *al-Kāfī*, MS Bibliothèque nationale, ar. 2999, fol. 42b.

Our model:
Stainless steel, polished.
Length: 119 mm.
(Inventory No. H 2.08)

[12] *at-Taṣrīf*, facsimile ed., vol. 2, p. 466; Leclerc, *La chirurgie d'Abulcasis*, op. cit., p. 23, fig. no. 9.

[13] İstanbul, Süleymaniye, collection Yeni Cami 924, fol. 95a.

[14] *'Ammār b. 'Alī*, op. cit., p. 165, 166, fig. no. 1.

Myrtle leaf

(*āsa*)

«This is used to lift and skin the pterygium, while scissors are used for cutting it off. Adhesions of the eyelids can also be cleaved with it.» (Ḫalīfa).
Our model was constructed after the illustrations in the manuscripts of the *Kitāb al-Kāfī* by Ḫalīfa al-Ḥalabī (written before 674/1275) and the sketch by J. Hirschberg[15].

Our model:
Brass and stainless steel.
Length: 110 mm.
(Inventory No. H 2.10))

Ḫalīfa, *al-Kāfī*, MS Yeni Cami no. 924, fol. 95 b.

Scalpel

for cutting off the pterygium and for removing adhesions in the inner corner of the eye

(*mibḍaʿ li-qaṭʿ aẓ-ẓafra wa-nutūw laḥm al-āmāq*)

Our model reproduces the sketch drawn by L. Leclerc[16] after the Paris manuscripts of az-Zahrāwī's (4th/10th cent.) book. The three additional illustrations shown here are from manuscripts Beşirağa[17] in Istanbul, besides Marsh and Huntington in Oxford[18].

Our model:
Brass and stainless steel.
Length: 141 mm.
(Inventory No. H 2.06)

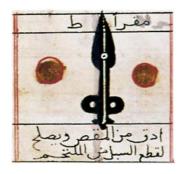
Kitāb at-Taṣrīf, facsimile ed., vol. 2, p. 485.

Albucasis. On Surgery and Instruments, p. 231, MS Hunt. (on the left), MS Marsh (on the right).

[15] MS Paris Bibliothèque nationale, ar. 2999, fol. 42 b; MS İstanbul, Süleymaniye, collection Yeni Cami 924, fol. 95 b; *ʿAmmār b. ʿAlī*, op. cit., p. 166, fig. no. 10, v. also p. 168.
[16] *La chirurgie d'Abulcasis*, op. cit., pp. 82-83, fig. no. 43.
[17] No. 502, v. facsimile ed., vol. 2, p. 485.
[18] Bodleian Library, Huntington 156 and Marsh 55; cf. *Albucasis. On Surgery and Instruments*, op. cit., p. 231.

Scissors (*kāz*)

One of the scissors used in ophthalmology; «for gathering (cutting off) the pterygium of the cornea circumference,» according to Ḫalīfa (before 674/1275). It is said to be thinner than the miqaṣṣ and thicker than the scissors called miqrāḍ (see below).
Our model was made after the illustration in the manuscripts of the *Kitāb al-Kāfī* and the sketch by Hirschberg[19].

Ḫalīfa, *al-Kāfī*, MS Yeni Cami no. 924, fol. 95a

Our model:
Stainless steel, riveted.
Length: 110 mm.
(Inventory No. H 2.14)

Scissors (*miqrāḍ*)

Another pair of scissors used in ophthalmology. It is «thinner than the miqaṣṣ» and «is used for cutting off the membrane (sabal) of the conjunctiva.»
Our model was prepared after the illustration in the manuscripts of the Kitāb al-Kāfī by Ḫalīfa al-Ḥalabī (before 674/1275) and the sketch by J. Hirschberg.[20]

MS Yeni Cami 924, fol. 95a.

Our model:
Stainless steel, riveted.
Length: 132 mm.
(Inventory No. H 2.15)

[19] MS Paris Bibliothèque nationale, ar. 2999, fol. 42b; MS İstanbul, Süleymaniye, collection Yeni Cami 924, fol. 95a; *ʿAmmār b. ʿAlī*…, p. 165, 166, fig. no. 3.
[20] MS Paris Bibliothèque nationale, ar. 2999, fol. 42b; MS Yeni Cami 924, fol. 95a; *ʿAmmār b. ʿAlī*, op. cit., p. 165, 166, fig. no. 2.

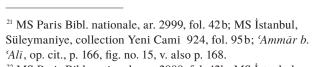
Lancet

(*mibḍaʿ*)

The lancet «with a round top» (*mudauwar ar-raʾs*) is used, according to Ḫalīfa, «for eradication of a blister (*širnāq*). The chalazion and the like are also cleaved with it.»
Our model was prepared after the illustration in the manuscripts of the *Kitāb al-Kāfī* by Ḫalīfa al-Ḥalabī (before 674/1275) and the sketch by J. Hirschberg[21].

MS Ḫalīfa,
Bibliothèque nationale,
ar. 2999, fol. 42 b.

Our model:
Brass and stainless steel.
Length: 128 mm.
(Inventory No. H 2.19)

Ḫalīfa, *al-Kāfī*,
MS Yeni Cami no.
924, fol. 95 b.

Scraper

(*miǧrad*)

«For scratching scabies and for removing conjunctival concretions. For that the ‘half rose’ can be used,» which is an instrument with a tip resembling half a «rose leaf» (above).
Our model was prepared after the illustrations in the two manuscripts[22] of the Kitāb al-Kāfī by Ḫalīfa al-Ḥalabī (before 674/1275) and the sketch by J. Hirschberg[23].

Our model:
Brass and stainless steel.
Length: 119 mm.
(Inventory No. H 2.21)

Ḫalīfa, *al-Kāfī*,
MS Yeni Cami no.
924, fol. 95 b.

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[21] MS Paris Bibl. nationale, ar. 2999, fol. 42 b; MS İstanbul, Süleymaniye, collection Yeni Cami 924, fol. 95 b; *ʿAmmār b. ʿAlī*, op. cit., p. 166, fig. no. 15, v. also p. 168.

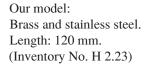
[22] MS Paris Bibl. nationale, ar. 2999, fol. 42b; MS İstanbul, Süleymaniye, collection Yeni Cami 924, fol. 95 b.

[23] *ʿAmmār b. ʿAlī*, op. cit., p. 166, fig. no. 14, v. also p. 168.

Axe (*ṭabar*)

A knife for bloodletting in the case of eye diseases, in particular «for opening the vein in the forehead (*li-faṣd al-ǧabha*): it is placed lengthwise on the vein (*yuḍaʿu ʿala l-ʿirq ṭūlan*) and the severing is done with the middle finger of the right hand (*wa-yuṯqabu bi-l-wusṭā min al-yad al-yumnā*).»[24]
Our model was prepared according to the sketch by J. Hirschberg, which he drew after the Paris manuscript[25] of the *Kitāb al-Kāfī* by Ḫalīfa (before 674/1275).

Hirschberg, *ʿAmmār b. ʿAlī…*, p. 166, fig. no. 11.

Our model:
Brass and stainless steel.
Length: 119 mm.
(Inventory No. H 2.22)

Ḫalīfa, *al-Kāfī*, MS Paris Bibl. nat., ar. 2999, fol. 42b.

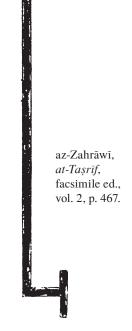
Cauter
for the vertex of the head
(*mikwāt al-yāfūḫ*)

A branding iron used for the treatment of eye diseases. According to Ḫalīfa «the head seam and the two veins on the two sides of the head are cauterised with this.»
Our model is based on the illustration in the two manuscripts[26] of the *Kitāb al-Kāfī* by Ḫalīfa al-Ḥalabī (before 674/1275) and the sketch by J. Hirschberg[27].

Our model:
Brass and stainless steel.
Length: 120 mm.
(Inventory No. H 2.23)

Ḫalīfa, *al-Kāfī*, MS Yeni Cami no. 924, fol. 95b.

Ḫalīfa, *al-Kāfī*, MS Paris Bibl. nat., ar. 2999, fol. 43.

[24] *ʿAmmār b. ʿAlī*, op. cit., p. 166, fig. no. 11, v. là-dessus 168; MS İstanbul, Süleymaniye, Yeni Cami 924, fol. 95b.
[25] MS Paris Bibliothèque nationale, ar. 2999, fol. 42b.
[26] MS Paris Bibl. nationale, ar. 2999, fol. 42b; MS İstanbul, Süleymaniye, collection Yeni Cami 924, fol. 95b.
[27] *ʿAmmār b. ʿAlī*, op. cit., p. 167, fig. no. 19, v. also p. 169.

Cauter

(*mikwāt*)

for cauterising the roots of the hair on the eyelid, when eyelashes grow into the eye (*fī kaiy ğafn al-ʿain iḏa nqalabat ašʿāruhā ilā dāḫil al-ʿain*).
Our model was constructed according to the sketch by L. Leclerc[28], which he drew after the illustrations in the Paris manuscripts of the *Kitāb at-Taṣrīf* by az-Zahrāwī (4th/10th cent.). It differs slightly from the illustration in the facsimile of the Istanbul manuscript (Beşirağa)[29].
For an instrument with the same function, see the following.

Our model:
Brass and stainless steel.
Length: 113 mm.
(Inventory No. H 2.03)

az-Zahrāwī, *at-Taṣrīf*, facsimile ed., vol. 2, p. 467.

Cauter

(*mikwāt*)

«For cauterising the locations of superfiuous eyelashes after the same have been pulled out (*li-kaiy mawāḍiʿ aš-šaʿr az-zāʾid baʿd natfihī*).»
Our model was developed from the illustrations of the manuscripts in Paris[30] and Istanbul[31] of the Kitāb al-Kāfī by Ḫalīfa al-Ḥalabī (before 674/1275) and the sketch by J. Hirschberg[32].

Our model:
Brass and stainless steel.
Length: 119 mm.
(Inventory No. H 2.24)

Ḫalīfa, *al-Kāfī*, MS Yeni Cami no. 924, fol. 95b.

[28] *La chirurgie d'Abulcasis*, p. 23*24 and fig. no. 10.
[29] *At-Taṣrīf*, facsimile ed. vol. 2, p. 467.
[30] Bibliothèque nationale, ar. 2999, fol. 43a.
[31] Süleymaniye-Bibl., collection Yeni Cami 924, fol. 95b.
[32] *ʿAmmār b.ʿAlī*, op. cit., p. 167, fig. no. 22, v. là-dessus p. 169.

Sickle (*minǧal*)

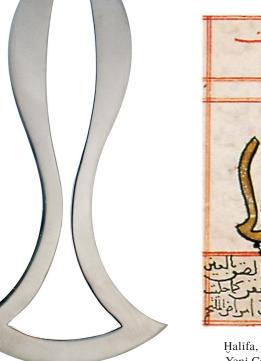
«For separating adhesions between the two lids. It is also used in the case of hare-eye (*šitra*)» (Ḫalīfa).
Our model was developed from the illustration in the [33] by Ḫalīfa al-Ḥalabī (before 674/1275) and the sketch by J. Hirschberg[34].

Ḫalīfa, *al-Kāfī*, MS Paris Bibl. nat., ar. 2999, fol. 42b.

Our model:
Stainless steel.
Length: 113 mm.
(Inventory No. H 2.09)

Ḫalīfa, *al-Kāfī*, MS Yeni Cami no. 924, fol. 95 b.

Raven's Beak

(Arabic *šaft*, Persian *ǧaft*, ‹courbé›)

«For removing whatever sticks to the eye or the inner side of the lid» (Ḫalīfa).
Our model was developed from the illustration in the *Kitāb al-Kāfī*[35] by Ḫalīfa al-Ḥalabī (before 674/1275) and the sketch by J. Hirschberg[36].

Ḫalīfa, *al-Kāfī*, MS Paris Bibl. nat., ar. 2999, fol. 43.

Our model:
Stainless steel.
Length: 120 mm.
(Inventory No. H 2.11)

Ḫalīfa, *al-Kāfī*, MS Yeni Cami no. 924, fol. 96.

[33] MS Paris Bibliothèque nationale, ar. 2999, fol. 42 b; MS İstanbul, Süleymaniye, collection Yeni Cami 924, fol. 95 b.
[34] *ʿAmmār b. ʿAlī*, op. cit.,p. 167, fig. no. 16, v. also p. 168.
[35] MS Bibl. nat., ar. 2999, fol. 43 a; MS Yeni Cami 924, fol. 96 a.
[36] *ʿAmmār b. ʿAlī*, op. cit.,p. 167, fig. no. 24, v. also p. 169.

Awn-tongs
(*kalbatān nuṣūlīya*)

«It is used when an awn or a similar object falls into the eye» (Ḫalīfa).
Our model was developed from the illustration in the two manuscripts of the *Kitāb al-Kāfī*[37] by Ḫalīfa al-Ḥalabī (before 674/1275) and the sketch by J. Hirschberg[38].

Our model:
Stainless steel, riveted.
Length: 122 mm.
(Inventory No. H 2.20)

Ḫalīfa, *al-Kāfī*, MS Paris Bibl. nat., ar. 2999, fol. 43a.

Ḫalīfa, *al-Kāfī*, MS Yeni Cami no. 924, fol. 96a.

Gatherer (*milqaṭ*)

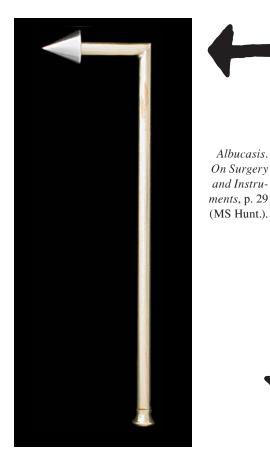
«This is used to gather (pluck) superfluous hair. It also pulls out any 'foreign body' that has fallen into the eye» (Ḫalīfa).
Our model was developed from the illustration in the Paris manuscript[39] of the Kitāb al-Kāfī by Ḫalīfa al-Ḥalabī (before 674/1275), which deviates in the depiction of the handle mechanism from that in the Istanbul manuscript.[40] J. Hirschberg[41] follows the Paris manuscript in his sketch.

Ḫalīfa, *al-Kāfī*, MS Paris Bibl. nat., ar. 2999, fol. 42b.

Our model:
Stainless steel, polished.
Length: 121 mm.
(Inventory No. H 2.16)

Ḫalīfa, *al-Kāfī*, MS Yeni Cami no. 924, fol. 95b.

[37] MS Paris Bibliothèque nationale, ar. 2999, fol. 43a; MS İstanbul, Süleymaniye, collection Yeni Cami 924, fol. 96a.
[38] *ʿAmmār b. ʿAlī*, op. cit.,p. 167, fig. no. 35, v. also p. 170.
[39] Bibliothèque nationale, ar. 2999, fol. 42b.
[40] Süleymaniye Kütüphanesi, coll. Yeni Cami 924, fol. 95b.
[41] *ʿAmmār b. ʿAlī*, op. cit.,p. 166, fig. no. 18, v. also p. 168 .

TREATMENT OF THE EARS, NOSE, AND RESPIRATORY PASSAGES

Cauter

called ‹point›

(*al-mikwāt allatī tusammā an-nuqṭa*)

It serves the treatment of earache by cauterising various points on the auricle
This instrument is depicted in two versions, one pointed and the other blunt. We have designed the pointed form after the illustrations in manuscript Huntington (Oxford)[1] and one of the Paris manuscripts[2] of az-Zahrāwī's (4th/10th cent.) book.

Our model:
Brass and stainless steel.
Length: 108 mm.
(Inventory No. H 4.08))

Albucasis. On Surgery and Instruments, p. 29 (MS Hunt.).

Cauter

called ‹point›

(*al-mikwāt allatī tusammā an-nuqṭa*)

It serves the treatment of earache.
The second, blunt version of this instrument was fashioned after the illustration in manuscript Marsh (Oxford),[3] one of the Paris manuscripts[4] and the facsimile edition[5] of az-Zahrāwī's (4th/10th cent.).

Our models:
Brass and stainless steel.
Length: 119 mm each.
(Inventory No. H 4.07 and H 4.01)

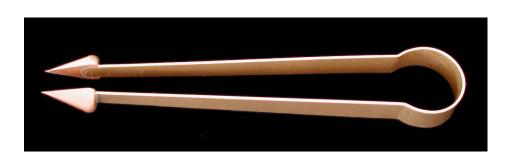
Kitāb at-Taṣrīf, facsimile ed., vol. 2, p. 467.

Albucasis. On Surgery and Instruments, p. 29 (MS Marsh).

[1] *Albucasis. On Surgery and Instruments*, p. 29.
[2] *La chirurgie d'Abulcasis*, pp. 16–17, fig. 5.
[3] *Albucasis. On Surgery and Instruments*, p. 29.
[4] *La chirurgie d'Abulcasis*, pp. 16–17, fig. 5 bis; cf. E. Gurlt, *Geschichte der Chirurgie und ihrer Ausübung*, vol. 1, Berlin 1898 (reprint Hildesheim 1964), p. 648.
[5] *At-Taṣrīf*, vol. 2, p. 464.

A fine Scalpel

(*mibḍaʿ raqīq*)

Our model:
Brass and stainless steel.
Length: 121 mm.
(Inventory No. H 4.09)

It serves «to disintegrate corns or seeds that have fallen into the ear (*qaṭʿ al-ḥubūb as-sāqiṭa fi l-uḏn*) and have swollen up due to the moisture inside the ear (*qad taraṭṭabat bi-buḫār al-uḏn*)» (az-Zahrāwī). Our model is constructed after the illustrations in the Paris manuscripts of the *Kitāb at-Taṣrīf* by az-Zahrāwī (4th/10th cent.) in the reproduction by L. Leclerc,[6] which correspond with the illustrations in one of the two Oxford manuscripts[7] and in MS Veliyeddin[8] at Istanbul.

az-Zahrāwī, *Taṣrīf*, MS Veliyeddin no. 2491, fol. 128 a.

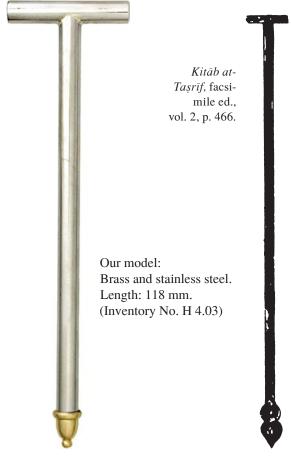
Tweezers (*ǧift*)

Our model (a):
Copper.
Length: 118 mm.
(Inventory No. H 4.02a)

Our model (b):
Brass.
Length: 130 mm.
(Inventory No. H 4.02b)

for removing foreign bodies from the auditory canal. Our model was constructed after the illustrations in the two Oxford manuscripts[9] of the *Taṣrīf* by az-Zahrāwī (4th/10th cent.) and after the illustration in MS Veliyeddin[10] in Istanbul.

az-Zahrāwī, *Taṣrīf*, MS Veliyeddin no. 2491, fol. 112 a.

[6] *La chirurgie d'Abulcasis*, p. 69, fig. no. 36; E. Gurlt, *Geschichte der Chirurgie,* vol. 1, p. 649, no. 33.
[7] Bodleian, Marsh 54, v. *Albucasis. On Surgery and Instruments*, p. 195.
[8] No. 2491, fol. 128 a.

[9] Bodleian, Marsh 54, v. *Albucasis. On Surgery and Instruments*, p. 195.
[10] No. 2491, fol. 128 a.

az-Zahrāwī, *Taṣrīf,* MS Paris Bibl. nat. ar. 2953, fol. 8b.

Kitāb at-Taṣrīf, facsimile ed., vol. 2, p. 466.

Cauter (*mikwāt*)

Our model:
Brass and stainless steel.
Length: 118 mm.
(Inventory No. H 4.03)

to be used in the case of nasal putrefaction (*natn al-anf*). Our model reproduces the illustration of one of the Paris manuscripts of az-Zahrāwī's (4th/10th cent.) book[11] (see above). The depiction of how to use it in the Turkish version by Šerefeddīn (see below) corresponds to the instruction given in the text; according to that, the nose itself is not cauterised, but cauterisation is done twice between the eyebrows and the hairline with an instrument «shaped like a nail» or «shaped like a pin».

Illustration from the Turkish version of the *Taṣrīf* de Šerefeddīn, MS İstanbul, Millet, Ali Emiri no. 79, fol. 24b.

[11] *At-Taṣrīf,* MS Paris Bibl. nat., ar. 2953, fol. 8b, cf. facsimile ed., vol. 2, p. 466; MS İstanbul, Bibl. de Beyazıt, collection Veliyeddin no. 2491, fol. 111a; Leclerc, *La chirurgie d'Abulcasis*, pp. 22–23, fig. no. 8.

Kitāb at-Taṣrīf, facsimile ed., vol. 2, p. 493.

‹Scissor-like Instrument›

(*āla tušbihu l-miqaṣṣ*)

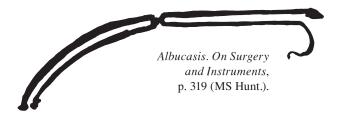
«for removing tonsils and other tumours of the pharynx.»
(*li-qaṭʿ waram al-lauzatain wa-mā yanbutu fi l-ḥalq min sāʾir al-aurām*).

Our model:
Stainless steel, riveted.
Length: 168 mm.
(Inventory No. H 4.05)

Our model is based on the sketch drawn by L. Leclerc[12] after the Paris manuscripts of the *Taṣrīf* by az-Zahrāwī (4th/10th cent.) and on the illustration in the manuscriptBeşirağa[13].

Scalpel (*mibḍaʿ*)
for removing tonsils (tonsillectomy)

To be used as an alternative to the previous instrument.

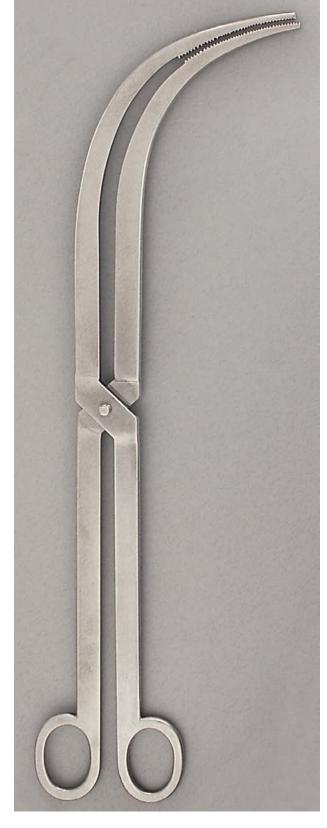
Our model is based on the description of the *Taṣrīf* by az-Zahrāwī (4th/10th cent.), on the sketch by Leclerc,[14] as well as the depiction in the facsimile edition[15] of the manuscript Beşirağa (İstanbul).

Our model:
Brass and stainless steel.
Length: 130 mm.
(Inventory No. H 4.04)

Kitāb at-Taṣrīf, facsimile ed., vol. 2, p. 493.

[12] *La chirurgie d'Abulcasis*, p. 106, fig. no. 67.
[13] Facsimile ed., vol. 2, p. 493; v. also *Albucasis. On Surgery and Instruments*, p. 303.

[14] *La chirurgie d'Abulcasis*, p. 106, fig. no. 68; v. also *Albucasis. On Surgery and Instruments*, p. 303.
[15] *At-Taṣrīf*, vol. 2, p. 493.

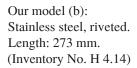
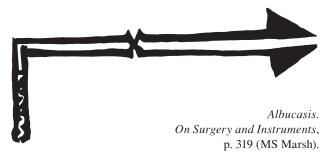
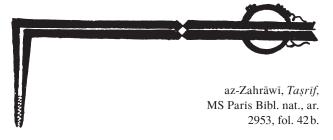
Albucasis. On Surgery and Instruments, p. 319 (MS Hunt.).

‹Instrument shaped like a hook

(*āla tušbihu l-kalālīb*)

A pair of tongs «for the extraction of foreign bodies from the pharyngeal cavity» (*fī iḫrāǧ al-ʿalaq an-nāšib fi l-ḥalaq*).

Of our two models, (a) was made according to the sketch drawn by L. Leclerc[16] after the diagram of the Paris manuscripts of the *Taṣrīf* by az-Zahrāwī (4th/10th century), and after the illustration in the MS Huntington at Oxford[17].
Model (b) was developed after the variant depictions in the Istanbul manuscripts at Beşirağa[18] and Veliyeddin[19] as well as Marsh[20] in Oxford.
K. Sudhoff established as early as in 1918 that the illustrations of this pair of tongs differ considerably also in the manuscripts of the Latin translation of az-Zahrāwī's book[21].

Our model (a):
Stainless steel, riveted.
Length: 320 mm.
(Inventory No. H 4.13)

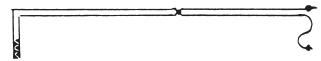
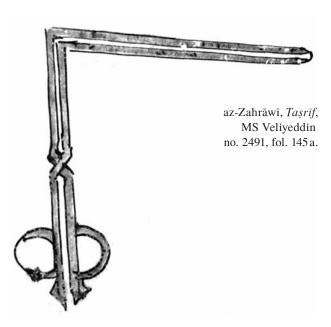
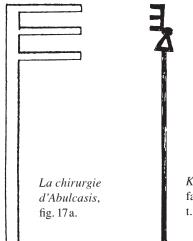
[16] *La chirurgie d'Abulcasis*, pp. 112–113, fig. no. 72.
[17] *Albucasis. On Surgery and Instruments*, p. 319.
[18] No. 502, v. *at-Taṣrīf*, vol. 2, p. 495.
[19] No. 2491, fol. 145a.
[20] *Albucasis. On Surgery and Instruments*, p. 319.
[21] K. Sudhoff, *Beiträge zur Geschichte der Chirurgie im Mittelalter*, 2nd part, Leipzig 1918, pp. 30–31 (reprint in: Islamic Medicine, vol. 37, pp. 180-181).

Albucasis.
On Surgery and Instruments,
p. 319 (MS Marsh).

az-Zahrāwī, *Taṣrīf,*
MS Paris Bibl. nat., ar.
2953, fol. 42b.

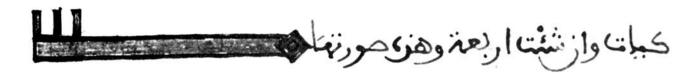
Kitāb at-Taṣrīf,
facsimile ed.,
vol. 2, p. 495.

az-Zahrāwī, *Taṣrīf*,
MS Veliyeddin
no. 2491, fol. 145a.

(Inventaire no. H 4.13)

Our model (b):
Stainless steel, riveted.
Length: 273 mm.
(Inventory No. H 4.14)

Cauter

(*mikwāt*)

For use «in the case of diseases of the lungs and coughing» (*fī kaiy maraḍ ar-riʾa wa-s-suʿāl*) from the *Kitāb at-Taṣrīf* by az-Zahrāwī.
The instrument with three pin-shaped projections at one end replaces the cauter called «point» (see above) when numerous, closely spaced applications are required.
Our model was developed according to the sketch drawn by L. Leclerc[22] after a manuscript of the *Taṣrīf* preserved in Paris. The illustrations reproduced here after our facsimile edition seem to be incorrect.[23] The instrument is completely omitted in manuscripts Paris Bibl. nat. ar. 2953 and Veliyeddin No. 2491.

Our model:
Brass and stainless steel.
Length: 120 mm.
(Inventory No. H 4.06)

La chirurgie d'Abulcasis, fig. 17 a.

Kitāb at-Taṣrīf, facsimile ed., t. 2, p. 468.

Albucasis. On Surgery and Instruments, p. 319 (MS Marsh, on the left, and MS Hunt., on the right).

كيات وان شئت اربعة وهذه صورتها

az-Zahrāwī, *Taṣrīf*, MS Vienne, Österreichische Nationalbibliothek, Cod. N. F. 476 a (Morocco 11th/17th century), fol. 14 a.

[22] *La chirurgie d'Abulcasis*, pp. 30–31, fig. no. 17.
[23] MS İstanbul, Bibliothèque de la Süleymaniye, collection Beşirağa 502, cf. facsimile ed., vol. 2, p. 468; v. also *Albucasis. On Surgery and Instruments*, p. 75; K. Sudhoff, *Beiträge zur Geschichte der Chirurgie im Mittelalter*, 2nd part, pp. 16–74, 22 pl., esp. pl. 2 (reprint. pp. 166–247, esp. p. 226, figs. 7–8).

DENTAL TREATMENT

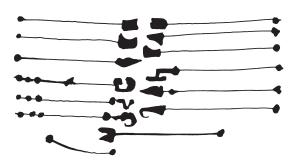
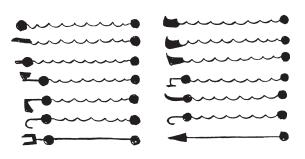
14 Raspatories
for the Removal of Tartar

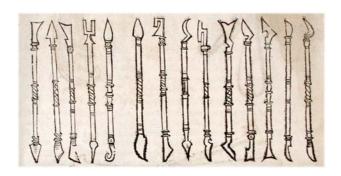
Our models:
Brass and stainless steel.
Length ca. 110 mm each.
(H 9.01 to H 9.14)

Among the dental instruments which az-Zahrāwī (4th/10th cent.) discusses and illustrates in sections 29 to 32 of the first chapter of his 30th treatise on medical treatment, the fourteen small instruments for removing tartar form a compact group. They appear, in various forms that differ considerably from one another, in Arabic and Latin manuscripts and in incunabula of the translation of the chapter on «surgery» (*al-ʿamal bi-l-yad*, «treatment») of az-Zahrāwī's book. The most striking feature is that in the European Zahrāwī-tradition the dental instruments often display an option for using them from both ends.[1]

Our models were made according to the drawings by L. Leclerc[2] after the illustrations in the manuscripts in az-Zahrāwī's book preserved in Paris as well as after the illustrations in the manuscript Beşirağa (Istanbul)[3] and the two manuscripts at Oxford.[4] In addition, the illustrations which K. Sudhoff[5] compiled from Latin manuscripts and incunabula were also consulted.

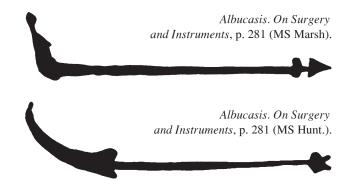
[1] Vincenzo Guerini, *A history of dentistry from the most ancient times until the end of the eighteenth century*, New York 1909, repr. Amsterdam 1967, pp. 125–138; K. Sudhoff, *Beiträge zur Geschichte der Chirurgie im Mittelalter*, 2nd part, pp. 68–74 (repr. pp. 218–224); Ch. Niel, *La chirurgie dentaire d'Abulcasis comparée à celle des Maures du Trarza*, in: La revue de stomatologie (Paris) 18/1911/169–180, 222–229 (repr. in: Islamic Medicine, vol. 37, pp. 145–156); Hans Zimmer, *Das zahnärztliche Instrumentarium des Albucasis*, in: Zahnärztliche Rundschau (Berlin) 48/1939/col. 69–71 (repr. in: Islamic Medicine, vol. 38, pp. 364–365).

[2] *La chirurgie d'Abulcasis*, 97–98, fig. no. 54 (14 figs.).
[3] No. 502, v. facsimile ed., op. cit., vol. 2, p. 490.
[4] Bodleian, Marsh 54 and Huntington 156, v. *Albucasis. On Surgery and Instruments*, p. 275.
[5] *Beiträge zur Geschichte der Chirurgie im Mittelalter*, 2nd part, pp. 68–70 (repr. pp. 218–220).

az-Zahrāwī, *Taṣrīf*, MS Veliyeddin no. 2491, fol. 139a.

Albucasis. On Surgery and Instruments, p. 275 (MS Hunt.).

Kitāb at-Taṣrīf, facsimile ed., vol. 2, p. 490.

Albucasis. On Surgery and Instruments, p. 275 (MS Marsh).

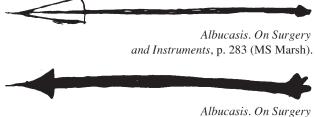
In the «Groß Chirurgei» by Walter Ryff (1559), this group of 14 instruments is shown as follows[6]:

[6] *Groß Chirurgei / oder Vollkommene Wundarznei*, Franckfurt am Meyn, 1559, fol. 38.

Instrument
‹like a small chisel›
(*āla tušbihu ʿatala ṣaġīra*)

Our model:
Brass and stainless steel.
Length: 117 mm.
(Inventory No. H 9.15)

Albucasis. On Surgery and Instruments, p. 281 (MS Marsh).

Albucasis. On Surgery and Instruments, p. 281 (MS Hunt.).

For levering out broken teeth that cannot be extracted with a pair of tongs.
Our model was prepared according to the sketch drawn by L. Leclerc[7] after the illustrations in the manuscripts preserved in Paris of az-Zahrāwī's book, as well as after the illustrations in the manuscript Beşirağa[8] and in the Oxford manuscripts Huntington[9] and Marsh[10].

Instrument
for levering out broken teeth

Our model:
Brass and stainless steel.
Length: 122 mm.
(Inventory No. H 9.16)

Serves the same purpose as the preceding instrument. Our model was prepared according to the sketch drawn by L. Leclerc[11] after the illustrations of the manuscripts of the *Kitāb at-Taṣrīf* by az-Zahrāwī (4th/10th cent.) which are preserved in Paris as well as after the illustrations of the Istanbul manuscript Beşirağa[12] and the Oxford manuscripts Huntington[13] and Marsh.[14]

Albucasis. On Surgery and Instruments, p. 283 (MS Marsh).

Albucasis. On Surgery and Instruments, p. 283 (MS Hunt.).

az-Zahrāwī, *Kitāb at-Taṣrīf*, facsimile ed., vol. 2, p. 491.

[7] *La chirurgie d'Abulcasis*, 101, fig. no. 57.
[8] No. 502, cf. facsimile ed., op. cit., vol. 2, p. 491.
[9] No. 156.
[10] No. 54, v. *Albucasis. On Surgery and Instruments*, p. 281, cf. K. Sudhoff, *Beiträge zur Geschichte der Chirurgie im Mittelalter*, 2nd part, p. 72 (repr., p. 222).
[11] *La chirurgie d'Abulcasis*, p. 101, fig. no. 58.
[12] No. 502, v. facsimile ed., op. cit. vol. 2, p. 491.
[13] No. 156.
[14] No. 54, v. *Albucasis. On Surgery and Instruments*, p. 283, cf. K. Sudhoff, *Beiträge zur Geschichte der Chirurgie im Mittelalter*, 2nd part., p. 72 (repr., p. 222).

The ‹Instrument with a fork›

(*āla ḏāt aš-šuʿbatain*)

Likewise for levering out broken teeth that cannot be extracted with tongs any more. Our model was prepared according to the sketch drawn by L. Leclerc[15] after the illustration in a Paris manuscript of the *Kitāb at-Taṣrīf* by az-Zahrāwī (4th/10th cent.), and after the illustration in the manuscript Huntington[16] in Oxford. This shape is confirmed by the Latin Zahrāwī-tradition.[17] The instrument is depicted neither in the Istanbul manuscripts Veliyeddin and Beşirağa nor in the Oxford copy Marsh.

Notre modèle:
Laiton et acier inoxydable.
Longueur: 116 mm.
(Inventaire no. H 9.17)

Albucasis. On Surgery and Instruments, p. 283 (MS Hunt.).

Instrument ‹like a large fish hook›

(*āla tušbihu ṣ-ṣinnāra al-kabīra*)

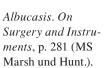
Our model: Brass and stainless steel.
Length: 115 mm. (Inventory No. H 9.18).

Serves the same purpose as the preceding instruments, for exposing and levering out broken teeth.
Our model was prepared according to the sketch drawn by L. Leclerc[18] after the illustrations in the manuscripts of the *Kitāb at-Taṣrīf* by az-Zahrāwī (4th/10th cent.) preserved in Paris as well as the illustrations in the Istanbul manuscript Beşirağa[19] and the Oxford manuscripts Marsh[20] and Huntington,[21] taking into account the Latin Zahrāwī-tradition[22].

Albucasis. On Surgery and Instruments, p. 285 (MS Hunt.).

az-Zahrāwī, *Taṣrīf*, MS Veliyeddin no. 2491, fol. 139 a.

az-Zahrāwī, *Kitāb at-Taṣrīf*, facsimile ed., vol. 2, p. 491.

[15] *La chirurgie d'Abulcasis*, p. 101, fig. no. 60.
[16] No. 156, v. *Albucasis. On Surgery* ..., p. 285.
[17] Ch. Niel, *La chirurgie dentaire d'Abulcasis,* p. 178. (repr., p. 154); K. Sudhoff, *Beiträge zur Geschichte der Chirurgie im Mittelalter*, 2nd part, p. 72 (repr., op. cit., p. 222).
[18] *La chirurgie d'Abulcasis*, p. 101, fig. no. 61.
[19] No. 502, v. facsimile ed., op. cit., vol. 2, p. 491.
[20] No. 54.
[21] No. 156, v. *Albucasis. On Surgery* ..., p. 283, 285.
[22] v. V. Guerini, *A history of dentistry*, p. 134; Ch. Niel, *La chirurgie dentaire d'Abulcasis,* p. 178 (repr., op. cit., p. 154); K. Sudhoff, *Beiträge zur Geschichte der Chirurgie im Mittelalter*, 2nd part, p. 72 (repr., op. cit., p. 222).

Model (a):
Stainless steel, riveted.
Length: 121 mm.
(Inventory No. H 9.21))

Albucasis. On Surgery and Instruments, p. 281 (MS Marsh und Hunt.).

Model (b):
Stainless steel, riveted.
Length: 144 mm.
(Inventory No. H 9.19)

Model (c):
Stainless steel, pivoted.
Length 144 mm.
(Inventory No. H 9.20)

Tongs

(*kalālīb*)

For the extraction of teeth and the removal of tooth fragments.
Our models (a, b, c) were prepared according to the sketches drawn by L. Leclerc[23] after the illustrations in the Paris manuscripts of az-Zahrāwī's *Taṣrīf*, also taking into account the illustrations in the Istanbul manuscript Beşirağa[24] and the Oxford manuscripts[25] as well as the Latin Zahrāwī-tradition[26].

az-Zahrāwī, *Taṣrīf*,
MS Paris Bibl. nat., ar. 2953.

[23] *La chirurgie d'Abulcasis*, p. 100, fig. nos. 55 and 56.
[24] No. 502, v. facsimile ed., op. cit. vol. 2, p. 491.
[25] Huntington 156 and Marsh 54, v. *Albucasis. On Surgery and Instruments*, p. 281.
[26] V. Guerini, *A history of dentistry*, p. 133; K. Sudhoff, *Beiträge zur Geschichte der Chirurgie im Mittelalter*, 2nd part, p. 70 (repr., op. cit., p. 220).

Tongs or Tweezers

(*ǧift*)

Our model:
Brass and Stainless Steel.
Length: 96 mm.
(Inventory No. H 9.22)

For the extraction of the roots of teeth and for the removal of jawbone fragments.
Our model was prepared according to the sketches drawn by L. Leclerc[27] after the illustrations of the Paris manuscripts of az-Zahrāwī's (4th/10th cent.) Taṣrīf, taking into account the illustrations in the Istanbul manuscript Beşirağa[28] and the two Oxford manuscripts Huntington and Marsh[29].

Albucasis. On Surgery and Instruments, p. 287 (MS Marsh).

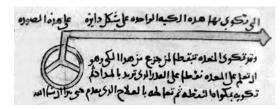
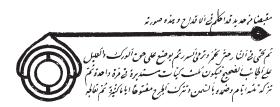
az-Zahrāwī, *Kitāb at-Taṣrīf,* facsimile ed., vol. 2, p. 491.

Albucasis. On Surgery and Instruments, p. 287 (MS Hunt.).

az-Zahrāwī, *Taṣrīf*, MS Paris Bibl. nat., ar. 2953, fol. 38 a.

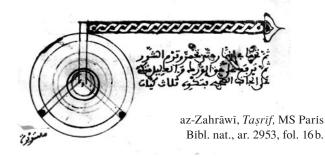
[27] *La chirurgie d'Abulcasis*, p. 101, fig. no. 62.
[28] No. 502, v. facsimile ed., op. cit. vol. 2, p. 491.
[29] No. 156 and no. 54, v. *Albucasis. On Surgery and Instruments*, p. 287.

TREATMENT OF NERVOUS DISORDERS

Our model:
Brass and stainless steel.
Length: 117 mm.
(Inventory No. H 7.01)

Cauter
with ring-shaped branding area

az-Zahrāwī, *Taṣrīf*,
MS Veliyeddin
no. 2491, fol. 115 a.

for the treatment of the lower area of the back «in the case of children with painful diseases of the spinal column.»[1]
Our model is based on the drawing made by L. Leclerc[2] after the illustrations in the Paris manuscripts of the Taṣrīf by az-Zahrāwī (4th/10th cent.), and after the illustrations in the manuscript Veliyeddin and those in the two copies at Oxford[3].

az-Zahrāwī, *Kitāb at-Taṣrīf*,
facsimile ed., vol. 2, p. 472.

Our model:
Brass and
stainless steel.
Length: 117 mm.
(Inventory No.H 7.02)

Cauter
for use in lumbar sciatica
(*āla li-kaiy ḥuqq al-wark*)

The round head of this instrument that is used in the case of pain in the lumbar region (sciatica) has a diameter of roughly half a span. Our model reproduces the illustration of the Istanbul manuscript Beşirağa[4] of az-Zahrāwī's (4th/10th cent.) *Kitāb at-Taṣrīf*. The illustrations of the Paris manuscripts as copied by L. Leclerc were also consulted.[5]

az-Zahrāwī, *Taṣrīf,* MS Paris
Bibl. nat., ar. 2953, fol. 16 b.

[1] K. Sudhoff, *Beiträge zur Geschichte …*, 2nd part, p. 22 and pl. II, fig. 13 (repr., op. cit., p. 172, 226).
[2] *La chirurgie d'Abulcasis*, p. 46, fig. no. 25.
[3] *Albucasis. On Surgery and Instruments*, p. 129.

[4] No. 502, v. facsimile ed., op. cit., vol. 2, p. 472.
[5] *La chirurgie d'Abulcasis*, p. 43, fig. no. 23; E. Gurlt, *Geschichte der Chirurgie*, pl. IV, no. 23; v. also *Albucasis. On Surgery …*, p. 119; K. Sudhoff, *Beiträge …*, 2nd part., p. 22 and pl. II, fig. 14 (repr., op. cit., p. 172, 226).

Our model:
Brass and stainless steel.
Length: 116 mm.
(Inventory No. H 7.05)

Cauter
for the treatment of epilepsy
(*mikwāt fī kaiy aṣ-ṣarʿ*)

az-Zahrāwī, *Taṣrīf*, MS Paris Bibl. nat., ar. 2953, fol. 38 a.

Our model was constructed after the illustrations in the Paris manuscripts of the *Kitāb at-Taṣrīf* by az-Zahrāwī (4th/10th cent.) as sketched by L. Leclerc[6] and after the illustration of the manuscript Veliyeddin.[7] In the facsimile edition of az-Zahrāwī's book the illustration is missing. The illustration in the manuscript Huntington,[8] at variance with the other manuscripts, shows an instrument bent at an angle which is meant for a similar purpose.
According to az-Zahrāwī, the common 'olive-cauter' (*mikwāt zaitūnīya*, see above, p. 39) is used for cauterisation of adult patients; the smaller instrument, shown here, is meant for boys.

az-Zahrāwī, *Taṣrīf*, MS Veliyeddin no. 2491, fol. 110 a.

[6] *La chirurgie d'Abulcasis*, op. cit.,p. 19–20, fig. 7.
[7] No. 2491, fol. 110 a.
[8] *Albucasis. On Surgery and Instruments*, op. cit.,p. 39.

TREATMENT OF THE URINARY TRACT

Our models:
Silver, length 23 (illustration) and 34 cm.
(Inventory No. H 5.01)

Catheter

(*qāṯāṭīr*)

«for relief when urine is retained in the bladder» (*fī ʿilāǧ al-baul al-muḥtabas fī l-maṯāna*). It is a very fine, smooth, silver tube of about one and a half spans in length which terminates in a beaker-like projection. With the help of a piece of cotton or wool which is inserted like a plug at the end of the tube and which is held by a thread laid out in double, the physician can let the accumulated urine flow off from the bladder. After applying some lubricating substance to it, he inserts the instrument into the male urinary tract and moves it, while pushing it forward, first with a downward movement and then upwards until the bladder is reached. Then he pulls the wool or cotton plug out through the narrow silver tube in order to let the urine, which has become free, flow off. The procedure is repeated until the bladder is emptied.
Our model is based on the illustrations in the manuscripts of the *Taṣrīf* by az-Zahrāwī (4th/10th cent.) in Istanbul[9] and Oxford[10] and on the drawing made by L. Leclerc[11] after the manuscripts preserved in Paris.

La chirurgie d'Abulcasis, fig. 69.

Albucasis. On Surgery and Instruments, p. 407 (MS Marsh).

az-Zahrāwī, *Taṣrīf*,
MS Veliyeddin no. 2491, fol. 107b.

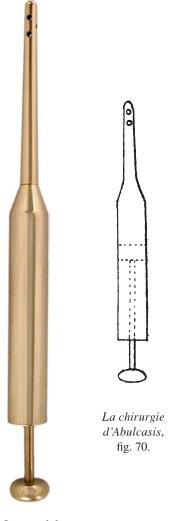
Reproduced here are the illustrations of two extant catheters made by the successors of this tradition: the first (a) by Cornelius Solingen (1706) and the second (b) by Whicker & Blaise (London, circa 1856).[12]

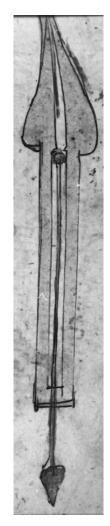
a)

b)

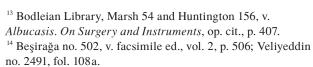
Elisabeth Bennion,
Antique medical instruments, pp. 77, 80.

[9] Veliyeddin 2491, fol. 157b.
[10] Bodleiana, Marsh 54, v. *Albucasis. On Surgery and Instruments*, p. 403.
[11] *La chirurgie d'Abulcasis*, p. 147, fig. no. 95; v. also O. Spies and H. Müller-Bütow, *Drei urologische Kapitel aus der arabischen Medizin*, in: Sudhoffs Archiv (Wiesbaden) 48/1964/248-259, esp. pp. 250-251; Abdul Salam Schahien, *Die geburtshilflich-gynäkologischen Kapitel aus der Chirurgie des Abulkasim. Ins Deutsche übersetzt und kommentiert*, doctoral thesis, Berlin 1937, pp. 11–12 (repr. in: Islamic Medicine, vol. 38, pp. 321-359, esp. pp. 331–332); M.S. Spink, *Arabian gynaecological, obstetrical and genito–urinary practice illustrated from Albucasis*, in: Proceedings of the Royal Society of Medicine (London) 30/1937/653–670, esp. p. 666 (repr. Islamic Medicine, vol. 38, pp. 303–320, esp. p. 316).
[12] Both in the Royal College of Surgeons of England, cf. Elisabeth Bennion, Antique medical instruments, London (Sotheby's) 1979, pp. 77, 80.

Stamp Syringe

(*zarrāqa* or *miḥqan*)

for instillation (*ḥaqn*) of the bladder. This apparatus is used for instilling medicines in liquid form through the urethra into the bladder. This is done for the treatment of ulcers, blood clots or pus in the bladder. The syringe is made of silver or ivory. The diameter of the cannula corresponds to the width of the urethra. As in the case of a modern syringe, a piston is passed through the broader part at the back, which is «used for drawing liquids as well as for giving injections» (Sudhoff). Towards the end of the cannula there are three holes on opposite sides, two on one side and one on the opposite side. Through these holes the liquid reaches the bladder while the injection is done.

Our model was constructed after the description in the *Taṣrīf* by az-Zahrāwī (4th/10th cent.) and after the illustrations in the manuscripts at Oxford[13] and Istanbul,[14] and also after the drawing made by L. Leclerc[15] after the illustrations in the Paris manuscripts.

La chirurgie d'Abulcasis, fig. 70.

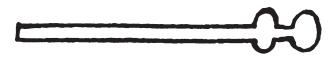
Kitāb at-Taṣrīf, facsimile ed., vol. 2, p. 506.

Our model:
Brass, synthetic material
Length: 133 mm
(Inventory No. H 5.06)

az-Zahrāwī, *at-Taṣrīf*, MS Veliyeddin

Fig. on the right: The form of the apparatus described by az-Zahrāwī continued through the centuries in different sizes and with differing functions and survives in the modern injection syringe. Some specimens of the 17th century made of silver, ivory, brass or wood can be found in the Germanisches Nationalmuseum at Nuremberg.

[13] Bodleian Library, Marsh 54 and Huntington 156, v. *Albucasis. On Surgery and Instruments*, op. cit., p. 407.

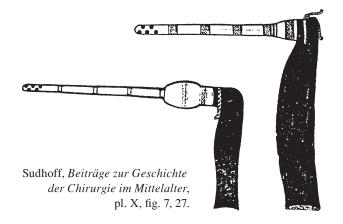
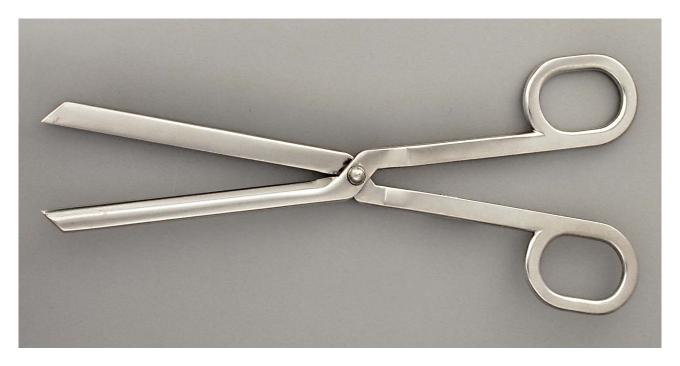
[14] Beşirağa no. 502, v. facsimile ed., vol. 2, p. 506; Veliyeddin no. 2491, fol. 108a.

[15] *La chirurgie d'Abulcasis*, op. cit., pp. 148–149, fig. no. 96; v. also K. Sudhoff, *Beiträge zur Geschichte der Chirurgie im Mittelalter*, op. cit., 2nd part, pp. 39–41 (repr., op. cit., pp. 189–191); Sami Hamarneh, *Drawings and pharmacy in al-Zahrāwī's 10th-century surgical treatise*, in: Contributions from the Museum of History and Technology (Washington, D.C.) 22/1961/81–94, esp. pp. 90–91.

Balloon Syringe

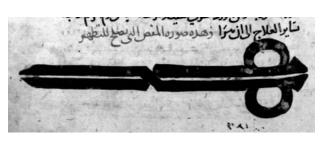
(*miḥqan*)

for bladder irrigation. In continuation of the preceding instrument for instillation of the bladder, az-Zahrāwī describes another type where the function of the piston is performed by a balloon-like hose. A ram-bladder, filled with the liquid medication, is tied to the cannula which is provided at the end with a groove for the piece of cord with which the bladder is fastened. If no ram-bladder is at hand, az-Zahrāwī recommends that a round piece be cut out of parchment (*qiṭʿat raqq*), that holes be made closely to each other near the edge and a strong piece of cord be drawn through the holes and, while pulling the cord together, the parchment be given the form of a moneybag (read *ṣurra* instead of *ṣufra*). Then this bag, filled with the liquid medicament, is tied to the cannula.
Model (a) was made after the description of the Arabic text[16] of the *Taṣrīf* by az-Zahrāwī (4th/10th cent.); model (b) after the illustrations known to us in its Latin translation.[17]

Model (a):
Brass.
Length: 170 mm.
(Inventory No. H 5.02 a)

az-Zahrāwī, *Kitāb at-Taṣrīf,* facsimile ed., vol. 2, p. 506.

az-Zahrāwī, *Taṣrīf*,
MS Veliyeddin no. 2491,
fol. 108 b.

Model (b):
Brass and leather.
Length: 157 mm.
(Inventory No. H 5.02b)

Sudhoff, *Beiträge zur Geschichte der Chirurgie im Mittelalter*,
pl. X, fig. 7, 27.

[16] v. facsimile ed. of MS Beşirağa, vol. 2, p. 506; v. also *La chirurgie d'Abulcasis*, op. cit., p. 149; *Albucasis. On Surgery and Instruments*, op. cit., p. 409; E. Gurlt, *Geschichte der Chirurgie*, vol. 1, pp. 632–633, fig. no. 71.
[17] V. K. Sudhoff, *Beiträge zur Geschichte der Chirurgie im Mittelalter*, 2nd part, pp. 43–44 and pl. X, figs. 7, 27 (repr., op. cit., pp. 193–194, 234). Sudhoff understands the instrument as an apparatus for the irrigation of the intestines, but not of the bladder.

Scissors

(*miqaṣṣ*)

Our model:
Stainless steel.
Length: 168 mm.
(Inventory No. H 5.07)

for the circumcision of boys. Our model was prepared after the illustration in one of the Paris manuscripts[18] of the *Taṣrīf* by az-Zahrāwī (4th/10th cent.) and after the drawing by L. Leclerc.[19] For comparison, the illustrations from the manuscripts Istanbul (Beşirağa[20] and Veliyeddin)[21] as well as Oxford (Hunt. and Marsh) are shown here.

az-Zahrāwī, *Kitāb at-Taṣrīf*, facsimile ed., vol. 2, p. 505.

Albucasis. On Surgery and Instruments, p. 401 (MS Hunt.).

az-Zahrāwī, *Taṣrīf*, MS Veliyeddin no. 2491, fol. 107.

Albucasis. On Surgery and Instruments, p. 401 (MS Marsh).

[18] Bibliothèque nationale, ar. 2953, fol. 54a.
[19] *La chirurgie d'Abulcasis*, pp. 143–146, fig. no. 94.
[20] No. 502, v. facsimile ed., vol. 2, p. 505.
[21] No. 2491, fol. 107.

GYNAECOLOGICAL INSTRUMENTS

In connection with the extraction of the fetus, az-Zahrāwī (4th/10th cent.) briefiy describes three instruments in his Taṣrīf. We are indebted to K. Sudhoff[1] for a helpful interpretation of the illustrations belonging to this subject, which are difficult to understand and in parts unclear in the manuscripts and incunabula of the Latin and French translations.

The first of the instruments mentioned and depicted by az-Zahrāwī under the heading *Ṣuwar al-ālāt allatī yuḥtāğu ilaihā fī iḫrāğ al-ğanīn*[2] («Depiction of the implements needed for the extraction of the fetus») is called *laulab yuftaḥu bihī fam ar-raḥim* («device in the form of a screw for opening the neck of the cervix). In modern technical literature, this apparatus is known as a «two-leaved speculum uteri»[3].

The second instrument is called «tongs-shaped» (*ʿalā šakl al-kalālīb*) by az-Zahrāwī. According to him, the third is another screw-like device «mentioned by the ancients» (*laulab āḫar ḏakarathu l-awāʾil*). About the material of which the first two instruments were made, az-Zahrāwī states that it was ebony (*ābanūs*) or box-tree wood (*ḫašab al-baqs*),[4] but he does not make any comment on the material of the instruments of «the ancients.» We know from archaeological finds from Pompeii that this was made of metal in Antiquity.[5]

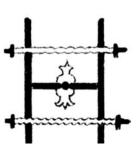
Various gynaecological instruments from *Taṣrīf* d'az-Zahrāwī, MS Paris Bibl. nat., ar. 2953, fol. 68.

az-Zahrāwī, *Taṣrīf*, MS Veliyeddin no. 2491, fol. 172 a.

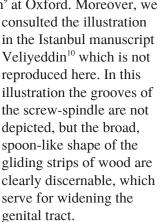
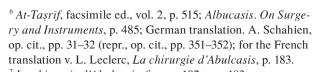
[1] *Beiträge zur Geschichte der Chirurgie im Mittelalter*, 2nd part, pp. 45–52 (repr., op. cit., pp. 195-202).

[2] *at-Taṣrīf*, facsimile ed., vol. 2, p. 515; *Albucasis. On Surgery and Instruments*, p. 485.

[3] E. Gurlt, *Geschichte der Chirurgie*, vol. 1, plate III, after p. 519, no. 99.

[4] A. Schahien, *Die geburtshilflich–gynäkologischen Kapitel aus der Chirurgie des Abulkasim*, p. 31 (repr., op. cit., p. 351).

[5] V. E. Gurlt, *Geschichte der Chirurgie*, vol. 1, p. 506, with further literature; J.S. Milne, *Surgical instruments in Greek and Roman times,* Oxford 1907, pl. 47–49; *Pompéi. Nature, sciences et techniques*, sous la direction de Annamaria Ciarallo, Ernesto de Carolis,… Alix Barbet, Milan 2001 (exhibition catalogue, Paris: Palais de la découverte), p. 256.

1. The

Two-leaves Speculum

About the illustration az-Zahrāwī says: «This is [like] the drawing of a press with which books are prepared. It consists of two screws at the end of two pieces of wood. But the two screws must be finer than the screws of the press and must be of ivory or box-tree wood, and the width of each of the two pieces of wood must be about two fingers, its thickness about one finger and their length must be one and a half spans, and at the middle of [each of] the two wooden pieces there should be two insets of the same type of wood, fixed firmly to them. Their length should be half a span or a little more, their width about two fingers or a little more. These are the two pieces of wood which are inserted into the cervix so that it is opened by them when you turn the two screws.»[6]

Our model:
Oak (for want of true box-tree wood) and brass, 30 × 30 cm.
(Inventory No. 6.04)

Our model was prepared according to the sketch drawn by L. Leclerc[7] after the illustrations in the Paris manuscripts of az-Zahrāwī's book, and after the illustrations in the manuscripts Beşirağa[8] at Istanbul and Huntington[9] at Oxford. Moreover, we consulted the illustration in the Istanbul manuscript Veliyeddin[10] which is not reproduced here. In this illustration the grooves of the screw-spindle are not depicted, but the broad, spoon-like shape of the gliding strips of wood are clearly discernable, which serve for widening the genital tract.

Kitāb at-Taṣrīf, facsimile ed., vol. 2, p. 515.

A variant with four threads is depicted in the Turkish adaptation by Šerefeddīn (1465) (see below; left: reconstruction sketch).

Šerefeddīn, MS İstanbul, Millet, Ali Emiri no. 79, fol. 113 a.

[6] *At-Taṣrīf*, facsimile ed., vol. 2, p. 515; *Albucasis. On Surgery and Instruments*, p. 485; German translation. A. Schahien, op. cit., pp. 31–32 (repr., op. cit., pp. 351–352); for the French translation v. L. Leclerc, *La chirurgie d'Abulcasis*, p. 183.
[7] *La chirurgie d'Abulcasis*, fig. no. 102 to p. 183.
[8] No. 502, v. facsimile ed., vol. 2, p. 515.
[9] No. 156, v. *Albucasis. On Surgery and Instruments*, p. 485.
[10] No. 2491, fol. 171 a.

2. The second instrument used in connection with the extraction of the fetus as described by az-Zahrāwī is called

‹Scissor-Speculum›

by K. Sudhoff, who describes it in the following words after the Latin translation: «It is a wooden instrument, shaped like a pair of tongs, which has appendages (additamenta), as long as one's hand and as broad as two fingers, that is to say quite large spoon-shaped branches of the speculum. These spoons (additamenta), in a closed state, are to be pushed into the vagina of the woman who is sitting on the bed with her legs hanging down. Then one should take hold of the other end of the scissor-speculum and open it with the hand, as one does while opening a pair of scissors; indeed open it as far as necessary to open the vulva and the vagina in order to see the portio. The physician and the midwife probably used to content themselves even with a thorough opening of the introitus vaginae. Particularly since even this is unnecessary, as a rule, when gynaecological operations are carried out.»[11]

Our model was made after the description in the text of the *Taṣrīf* by az-Zahrāwī[12] and after the figure in manuscript Marsh[13] (Oxford).

Our model:
Stainless steel, riveted.
Length: 194 mm.
(Inventory No. H 6.01)

Albucasis. On Surgery and Instruments, p. 487 (MS Marsh).

Cod. lat. Monacensis 161 (XIII^e s.) fol. 18 a. D'après Sudhoff, *Beiträge zur Geschichte der Chirurgie im Mittelalter,* 2^nd part, p. 51.

[11] *Beiträge zur Geschichte der Chirurgie im Mittelalter*, 2nd part, p. 51 (repr., op. cit., p. 201); v. also A. Schahien, op. cit., p. 32 (repr., op. cit., p. 352).

[12] v. facsimile ed., vol. 2, p. 515; v. also Leclerc, *La chirurgie d'Albucasis*, pp. 183–184, fig. no. 103.

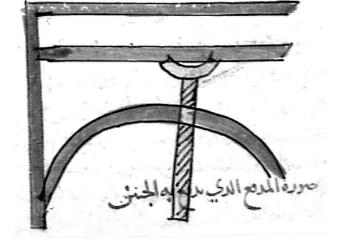
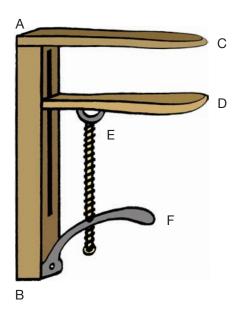
[13] No. 56, v. *Albucasis. On Surgery…*, op. cit.,p. 487.

Our model:
Oak, brass and stainless steel.
Height: 25 cm.
(Inventory No. H 6.05)

3. The third instrument which az-Zahrāwī mentions in connection with the extraction of the fetus and calls the

Instrument ‹of the Ancients›

(*ālāt al-awā'il*)[14]

without, however, describing it. Even the illustrations in the available manuscripts do not offer a clear idea about this apparatus. K. Sudhoff[15] made every effort and succeeded in finding an explanation for the illustrations preserved in manuscripts and incunabula. He found that the drawing which is difficult to interpret even in some of the Arabic manuscripts and which in the Latin copies resembles a street-lantern, must originally have represented «a spoon-speculum with a screw arrangement for unscrewing its spoon-branches as they are preserved from Pompeii as speculum trivalve.»[16] Only in the manuscript Marsh 54, which he knew through the Latin translation by Channing[17], did he find [**77**] «a screw arrangement of a similar nature where one could, if so inclined, really find what is essential.»[18] Among the Arabic manuscripts of the

[14] *At-Taṣrīf*, facsimile ed., vol. 2, p. 515.
[15] *Beiträge zur Geschichte der Chirurgie im Mittelalter*, 2nd part, pp. 51–52 (repr., op. cit., p. 201–202).
[16] Ibid., p. 52 (repr., p. 202).
[17] *Albucasis de Chirurgia Arabice et Latine* Cura Johannes Channing, 2 vols, London 1778.

30th chapter of az-Zahrāwī's *Taṣrīf* which are accessible to me at present, I believe that the illustration of the Istanbul manuscript Veliyeddin comes the closest to reality:

az-Zahrāwī, *Taṣrīf*, MS Veliyeddin no. 2491, fol. 171 b.

With this it is possible to reconstruct the instrument as follows:

The two arcs E and F have the function of securing the screw with which the lower and movable of the two spoon-branches is screwed upwards and downwards. This branch must have acquired its ability to slide up or down through a slot in the beam AB or through a ring surrounding the beam.
After these deliberations it should not be difficult to realise the connection between the distorted illustrations in a few Arabic and in almost all Latin manuscripts, on the one hand, and the original illustration, on the other.

An example of the later «lantern» pictures where the «lantern» had obviously been installed erroneously from an independent illustration (of another speculum ?):

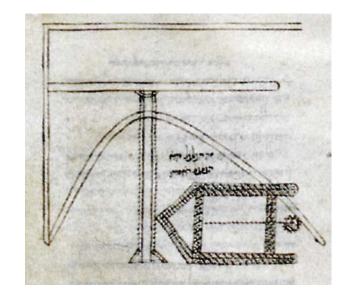
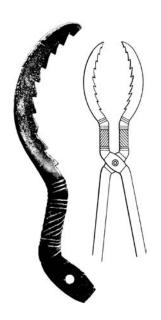
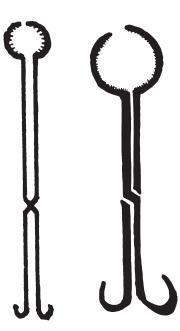



Fig. from the *Taṣrīf*'s Hebrew translation by Shemtov b. Isaac of Tortosa (1258), copy from the early 15th century[19].

[18] K. Sudhoff, op. cit., p. 52 (repr., p. 202).
[19] MS Paris Bibl. nat., heb. 1163, fol. 222a.

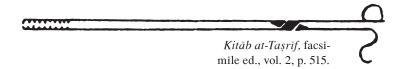
Part of a comparable instrument from the alleged «physician's grave of Ephesus», Byzantine (?). Copper alloy. After S. Zimmermann, E. Künzl: *Die Antiken der Sammlung Mayer-Steinegg in Jena I*, Jahrbuch des Röm.-Germ. Zentralmuseums Mainz, 38/2, 1991 (Mainz 1995).

Kitāb at-Taṣrīf, facsimile ed., vol. 2, p. 515.

Albucasis. On Surgery and Instruments, p. 491 (MS Hunt.).

Cephalotribe

(*mišdāḫ*)

An instrument resembling obstetric forceps «for crushing the head of a fetus» (*yušdaḫ bihī raʿs al-ǧanīn*) in case of miscarriages.
Our model is based on the sketch by L. Leclerc[20] which he drew after the illustrations in the Paris manuscripts of the Taṣrīf by az-Zahrāwī (4th/10th cent.) and on the illustration in the Istanbul manuscript Beşirağa[21] (see above). By way of comparison, the illustration of the Oxford manuscript Huntington[22] is reproduced here.

Our model:
Stainless steel, riveted.
Length: 214 mm.
(Inventory No. H 6.02)

[20] *La chirurgie d'Abulcasis*, p. 184, fig. no. 106.
[21] No. 502, v. facsimile ed., vol. 2, p. 515.
[22] v. *Albucasis. On Surgery and Instruments*, p. 491; v. also A. Schahien, *Die geburtshilflich–gynäkologischen Kapitel aus der Chirurgie des Abulkasim*, pp. 33–34 (repr., op. cit., pp. 353–354); K. Sudhoff, *Beiträge zur Geschichte der Chirurgie ...*, 2nd part, p. 53 (repr., op. cit., p. 203).

Kitāb at-Taṣrīf, facsimile ed., vol. 2, p. 515.

Model (a):
Stainless steel, riveted.
Length: 254 mm.
(Inventory No. H 6.03)

Cephalotribe

(*mišdāḫ*)

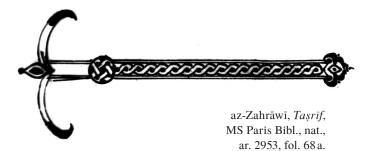
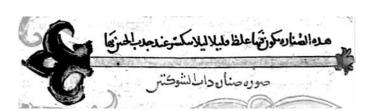
Another pair of tongs with the same function, which az-Zahrāwī describes in the following manner: «It is similar to a pair of scissors. As you see, it has teeth at the end, and sometimes it is made long like tongs. In this illustration it has, as you see, teeth like the teeth of a saw. With this you cut and crush (the head).»[23]

Our models (a, b) are based on the Istanbul manuscript Beşirağa[24] of the *Taṣrīf* by az-Zahrāwī (4th/10th cent.) and on a sketch drawn by L. Leclerc[25] after one of the Paris manuscripts of that book. For comparison, the illustration from the Paris manuscript ar. 2953[26] is reproduced here.

Model (b):
Stainless steel, riveted.
Length: 198 mm.
(Inventory No. H 6.06)

az-Zahrāwī, *Taṣrīf,* MS Paris Bibl. nat., ar. 2953, fol. 67 b.

[23] A. Schahien, *Die geburtshilflich–gynäkologischen Kapitel aus der Chirurgie des Abulkasim*, p. 34 (repr., op. cit., p. 354).
[24] No. 502, v. facsimile ed., vol. 2, p. 515.
[25] *La chirurgie d'Abulcasis*, op. cit., p. 183, fig. no. 107.
[26] Bibliothèque nationale, ar. 2953, fol. 67 b.

‹Hook with two horns›

(*ṣinnāra ḏāt aš-šaukatain*)

An instrument for the extirpation of dead foetuses from the uterus.
Our model is based on the illustrations, one from each, of the Paris[27] Istanbul[28] and Oxford[29] manuscripts and the drawing by L. Leclerc.[30]

Our model:
Brass and stainless steel.
Length: 196 mm.
(Inventory No. H 6.07)

az-Zahrāwī, *Taṣrīf*,
MS Paris Bibl., nat.,
ar. 2953, fol. 68 a.

Albucasis. On Surgery and Instruments,
p. 495 (MS Marsh).

az-Zahrāwī, *Taṣrīf*, MS
Veliyeddin no.2491, fol. 172b.

[27] Bibliothèque nationale, ar. 2953, fol. 68a.

[28] Süleymaniye Kütüphanesi, collection Beşirağa 502, v. facsimile ed., vol. 2, p. 516.

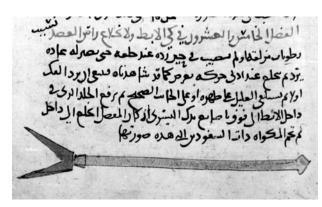
[29] Bodleian Library, Marsh 54, v. *Albucasis. On Surgery and Instruments*, p. 495.

[30] *La chirurgie d'Abulcasis*, p. 184, fig. no. 110; v. also K. Sudhoff, *Beiträge zur Geschichte der Chirurgie im Mittelalter*, 2nd part, pp. 54–55 (repr., op. cit., p. 204–205); A. Schahien, *Die geburtshilflich–gynäkologischen Kapitel aus der Chirurgie des Abulkasim*, p. 34 (repr., op. cit., p. 354).

ORTHOPAEDICS

Cauter

with ‹two spits›

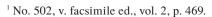
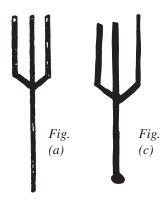
(*mikwāt ḏāt as-saffūdain*)

Our model:
Brass and stainless steel.
Length: 120 mm.
(Inventory No. H 3.03)

Kitāb at-Taṣrīf, facsimile ed., vol. 2, p. 479 (on the margin).

for branding the armpit (*li-kaiy al-ibṭ*) in case of luxations (dislocations).
Our model reproduces one of the illustrations in the Istanbul manuscript Beşirağa[1] of the *Kitāb at-Taṣrīf* by az-Zahrāwī (4th/10th cent.) and corresponds with the sketch drawn by L. Leclerc[2] after the manuscripts of the book preserved in Paris.

az-Zahrāwī, *Taṣrīf*, MS Veliyeddin no. 2491, fol. 114 a.

Cauter

with ‹three spits›

(*mikwāt ḏāt ṯalāṯ safāfīd*)

Our model:

Likewise for branding the armpit (*li-kaiy al-ibṭ*) in case of luxations (dislocations).
Our model corresponds with the drawing made by L. Leclerc[3] after the manuscripts of the *Kitāb at-Taṣrīf* by az-Zahrāwī (4th/10th cent.) preserved in Paris and takes into account the illustrations in the Latin translations of the book. The illustrations reproduced here are taken from the Arabic copies of the work in the collections Beşirağa[4] (a) and Veliyeddin[5] (b) at Istanbul as well as from the copy of the Bodleian at Oxford[6] (c).

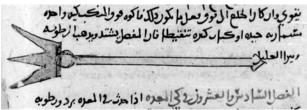



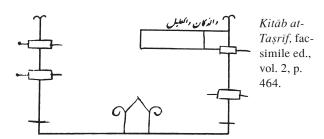
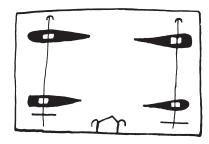
Fig. (a)

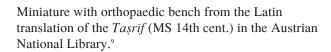
Fig. (c)

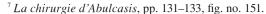
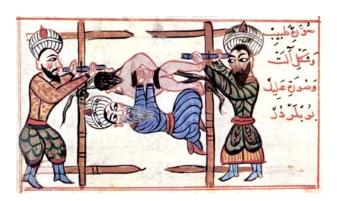
Fig. (b)

[1] No. 502, v. facsimile ed., vol. 2, p. 469.
[2] *La chirurgie d'Abulcasis*, p. 31, fig. no. 17'.
[3] *La chirurgie d'Abulcasis*, p. 31–32, fig. no. 17''.
[4] No. 502, v. facsimile ed., vol. 2, p. 469 in the margin.
[5] No. 2491, fol. 114 b.
[6] Huntington no. 156, v. *Albucasis. On Surgery and Instruments*, p. 79; v. also E. Gurlt, *Geschichte der Chirurgie*, vol. 1, pp. 623, 648, plate IV, no. 17b; K. Sudhoff, *Beiträge zur Geschichte der Chirurgie im Mittelalter*, 2nd part, p. 22 and plate II, fig. 12 (repr., op. cit. p. 172, 226).

Orthopaedic bench

‹for the treatment of luxations (dislocations) of the dorsal vertebrae›

(*fī ʿilāğ fakk ḫaraz aẓ-ẓahr*)

Our model:
Wood, carved figure.
(Inventory No. H 3.05)

Our model was constructed according to the drawing made by L. Leclerc[7] after the illustrations in the Paris manuscripts of the *Taṣrīf* and after the description in az-Zahrāwī's book[8].

The illustration included in the *Taṣrīf* by az-Zahrāwī (4th/10th cent.) is the last one in the book.

Kitāb at-Taṣrīf, facsimile ed., vol. 2, p. 464.

Albucasis. On Surgery and Instruments, p. 817 (MS Hunt.).

Miniature with orthopaedic bench from the Latin translation of the *Taṣrīf* (MS 14th cent.) in the Austrian National Library.[9]

Miniature with orthopaedic bench from the Turkish version of the text by az-Zahrāwī through Šerefeddīn (MS Paris).[10]

[7] *La chirurgie d'Abulcasis*, pp. 131–133, fig. no. 151.
[8] *At-Taṣrīf*, facsimile ed., vol. 2, pp. 563–564; v. also K. Sudhoff, *Beiträge ...*, 2nd part, p. 67 (repr., op. cit., p. 217).
[9] Codex S.N. 2641, facsimile ed., Graz 1979, fol. 76b.

[10] P. Huard, M.D. Grmek, *Le premier manuscrit chirurgical turc rédigé par Charaf ed-Din (1465) et illustré de 140 miniatures*. Présentation française. Paris 1960, fig. 127.

GENERAL SURGERY

Our model:
Brass and stainless steel.
Length: 147 mm.
(Inventory No. H 3.06)

Scarificator

(*mišraṭ*)

for cutting off and removing cysts, sebaceous cysts and tumours (*yušraṭ bihī as-silaʿ wa-l-aurām*). az-Zahrāwī (4th/10th cent.) knows three different sizes (v. fig. on the right).
Our model representing the largest of the three forms according to the *Kitāb at-Taṣrīf*, was made on the basis of the sketch drawn by L. Leclerc[1] after the illustrations in the Parisian manuscripts. For comparison, the illustration from one of the Oxford manuscripts[2] is added here (on the left).

Albucasis.
On Surgery and Instruments,
p. 355 (MS Marsh).

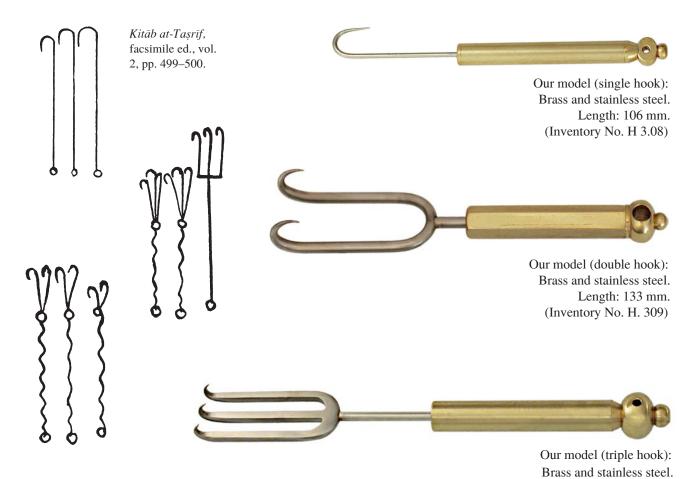
az-Zahrāwī, *Taṣrīf*, MS
Veliyeddin no. 2491, fol. 150 b.

Scalpel

(*mibḍaʿ*)

Our model: Brass and stainless steel.
Length: 118 mm. (Inventory No. H 3.07)

for the extraction of arteries at the temples (*fī sall aš-širyānain allaḏain fi l-aṣdāġ*).
Our model is based on the drawing made by L. Leclerc[3] after the illustrations in the Paris manuscripts of the *Taṣrīf* by az-Zahrāwī (4th/ 10th cent.). For comparison, the depictions from the Istanbul manuscripts Beşirağa[4] and Ahmet III are added here

az-Zahrāwī, *Taṣrīf,* MS Ahmet III, 1990, fol. 35 a.

az-Zahrāwī, *Taṣrīf,* facsimile ed., vol. 2, p. 479.

[1] *La chirurgie d'Abulcasis*, p. 126, fig. no. 83; cf. K. Sudhoff, *Beiträge …*, 2nd part, p. 35 (repr., op. cit. p. 185).
[2] Bodleian Library, Marsh 54, v. *Albucasis. On Surgery and Instruments*, p. 355.

[3] *La chirurgie d'Abulcasis*, p. 62, fig. no. 31; cf. *Albucasis. On Surgery and Instruments*, p. 179; v. also E. Gurlt, *Geschichte der Chirurgie*, vol. 1, p. 625.
[4] No. 502, v. facsimile ed., vol. 2, p. 478–479.

Kitāb at-Taṣrīf, facsimile ed., vol. 2, pp. 499–500.

Our model (single hook): Brass and stainless steel. Length: 106 mm. (Inventory No. H 3.08)

Our model (double hook): Brass and stainless steel. Length: 133 mm. (Inventory No. H. 309)

Our model (triple hook): Brass and stainless steel. Length: 153 mm. (Inventory No. H 3.10)

Hook

(*ṣinnāra*)

for lifting vessels. Az-Zahrāwī (4th/10th cent.) describes in his *Taṣrīf* three types of hooks: a simple one with a single prong, one with two prongs and one with three prongs. Of each type, he mentions three sizes: small, medium and large (*ṣinnāra ṣaġīra, ṣinnāra «wasaṭ», ṣinnāra kabīra*). Our models represent the «large» size in each case. They are based on the drawings made by L. Leclerc[5] after the manuscripts of the *Taṣrīf* by az-Zahrāwī (4th/10th cent.) available in his time at Paris and on the illustrations in other manuscripts in Istanbul[6] and Oxford[7].

az-Zahrāwī, *Taṣrīf*, MS Veliyeddin no. 2491, fol. 150 b.

[5] *La chirurgie d'Abulcasis*, p. 126, fig. no. 78, 80, 81.

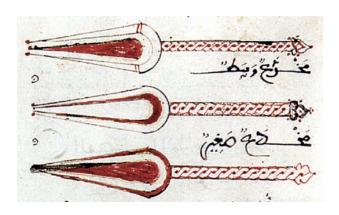
[6] Süleymaniye Kütüphanesi, collection Beşirağa 502, v. facsimile ed., vol. 2, p. 499–500.

[7] Bodleian Library, Huntington 156 and Marsh 54, v. *Albucasis. On Surgery…*, pp. 351–355; v. also K. Sudhoff, *Beiträge…*, 2nd part, pp. 34–35 (repr., op. cit., pp. 184–185).

Covered Scalpel

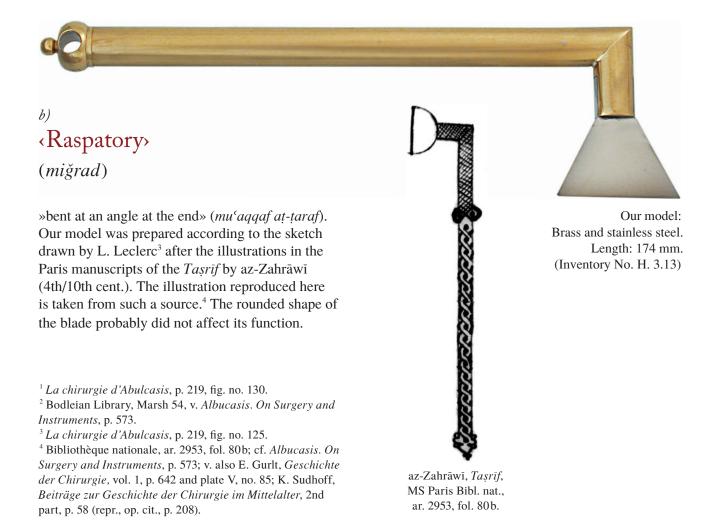
‹secret chamber› (*miḫdaʿ*)

Our model:
Copper, brass and steel,
length: 125 mm.
(Inventory No. H 3.11)

According to the description by az-Zahrāwī[8] (4th/10th cent.) and his illustrations in the *Kitāb at-Taṣrīf*, this instrument consists of a blade hidden inside an ellipsoid shell. It can be pushed out of the shell up to the desired length and pulled back again into the shell so that the patient does not notice it. Our model was constructed after the description by az-Zahrāwī, following the illustrations in the Istanbul manuscript Veliyeddin[9] and the Oxford manuscript Marsh[10], and after the sketch drawn by L. Leclerc[11] after the illustrations in the manuscripts of the *Taṣrīf* available in his time at Paris. This instrument was also in use in three sizes (v. fig. below, on the left).

Albucasis. On Surgery and Instruments, p. 357 (MS Marsh).

az-Zahrāwī, *Taṣrīf*, MS Veliyeddin no. 2491, fol. 151a.

az-Zahrāwī, *Taṣrīf*, MS Paris Bibl. nat., ar. 2953, fol. 68a.

[8] *At-Taṣrīf*, facsimile ed., vol. 2, p. 500.
[9] Veliyeddin 2491, fol. 151a.
[10] Bodleian Library, Marsh 54, v. *Albucasis. On Surgery and Instruments*, p. 357.
[11] *La chirurgie d'Abulcasis*, p. 127, fig. no. 84; v. also E. Gurlt, *Geschichte der Chirurgie*, vol. 1, p. 630, plate IV, no. 62; K. Sudhoff, *Beiträge zur Geschichte der Chirurgie im Mittelalter*, 2nd part, pp. 35–36 (repr., op. cit. pp. 185–186).

Our model:
Brass and stainless steel. Length: 174 mm.
(Inventory No. H 3.12)

a)

‹Peeler›

or ‹Scraper› (Raspatorium)

(*miğrad*)

for the incision of bones (*li-qaṭʿ al-ʿiẓām*).
Our model was prepared according to the sketch drawn by L. Leclerc[1] after the illustrations in the Paris manuscripts of the *Taṣrīf* by az-Zahrāwī (4th/10th cent.). The illustration added here goes back to one of the Oxford manuscripts.[2]

Albucasis. On Surgery and Instruments, p. 573 (MS Marsh).

Fig. from the Latin MS, Munich, cod. lat. 161, after K. Sudhoff, *Beiträge …*, 2nd part, plate XVII, 8-9.

b)

‹Raspatory›

(*miğrad*)

»bent at an angle at the end» (*muʿaqqaf aṭ-ṭaraf*).
Our model was prepared according to the sketch drawn by L. Leclerc[3] after the illustrations in the Paris manuscripts of the *Taṣrīf* by az-Zahrāwī (4th/10th cent.). The illustration reproduced here is taken from such a source.[4] The rounded shape of the blade probably did not affect its function.

Our model:
Brass and stainless steel.
Length: 174 mm.
(Inventory No. H. 3.13)

az-Zahrāwī, *Taṣrīf*, MS Paris Bibl. nat., ar. 2953, fol. 80b.

[1] *La chirurgie d'Abulcasis*, p. 219, fig. no. 130.
[2] Bodleian Library, Marsh 54, v. *Albucasis. On Surgery and Instruments*, p. 573.
[3] *La chirurgie d'Abulcasis*, p. 219, fig. no. 125.
[4] Bibliothèque nationale, ar. 2953, fol. 80b; cf. *Albucasis. On Surgery and Instruments*, p. 573; v. also E. Gurlt, *Geschichte der Chirurgie,* vol. 1, p. 642 and plate V, no. 85; K. Sudhoff, *Beiträge zur Geschichte der Chirurgie im Mittelalter*, 2nd part, p. 58 (repr., op. cit., p. 208).

c)

‹Raspatory›

(*miğrad*)

Our model:
Brass and stainless steel.
Length: 150 mm.
(Inventory No. H 3.14)

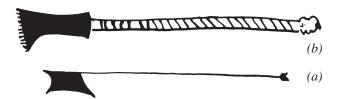
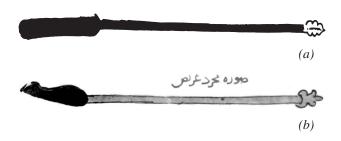
«with indentation» (*fīhi tağwīf*), i.e. with a concave blade.
Our model is based on the sketch drawn by L. Leclerc[5] after the illustrations in the Paris manuscripts of the *Taṣrīf* by az-Zahrāwī (4th/10th cent.). The illustrations reproduced here are from the copies Huntington (a) and Marsh (b) in Oxford[7].

(b)

(a)

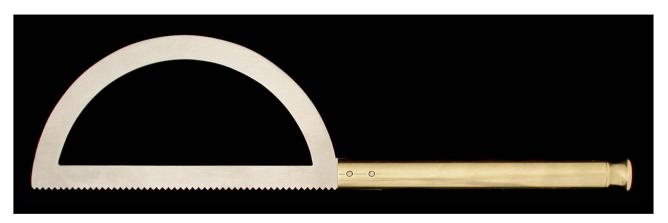
d)

‹Broad Raspatory›

(*miğrad ʿarīḍ*)

Our model:
Brass and stainless steel.
Length: 182 mm.
(Inventory No. H 3.15)

Our model is based on the sketch drawn by L. Leclerc[8] after the illustrations in the Paris manuscripts of the *Taṣrīf* by az-Zahrāwī (4th/10th cent.). The illustrations reproduced here[9] come from the manuscripts Veliyeddin[10] (a) at Istanbul and Marsh[11] (b) at Oxford.

(a)

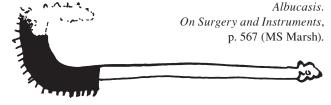
(b)

[5] *La chirurgie d'Abulcasis*, p. 219, fig. no. 124.
[6] No. 502, v. facsimile ed., vol. 2, p. 528.
[7] Bodleian Library, Huntington 156 et Marsh 54, v. *Albucasis. On Surgery and Instruments*, p. 571; v. also E. Gurlt, *Geschichte der Chirurgie*, vol. 1, p. 642 and plate V, no. 84; K. Sudhoff, *Beiträge zur Geschichte der Chirurgie im Mittelalter*, 2nd part, p. 58 (repr., op. cit., p. 208).

[8] *La chirurgie d'Abulcasis*, p. 219, fig. no. 126.
[9] No. 2491, fol. 185b; cf. facsimile ed., vol. 2, p. 528.
[10] Marsh 54, v. *Albucasis. On Surgery and Instruments*, p. 571; v. also E. Gurlt, *Geschichte der Chirurgie*, vol. 1, p. 642 and plate V, no. 86.

e) ‹Compact Hacksaw›

(*minšār muḥkam*)

Our model:
Brass and stainless steel.
Length: 245 mm.
(Inventory No. H 3.16)

Our model is based on the sketch drawn by L. Leclerc[11] after the illustrations in the Paris manuscripts of the *Taṣrīf* by az-Zahrāwī (4th/10th cent.) and following the illustration in the Istanbul manuscript Veliyeddin.[12] According to az-Zahrāwī, the bow and the blade are of «iron» (*ḥadīd*), the handle of box-tree wood (*baqs*), «turned and fastened well».

az-Zahrāwī, *Taṣrīf*, MS Veliyeddin no. 2491, fol. 185b.

f) Padsaw

(*minšār*)

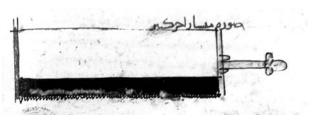
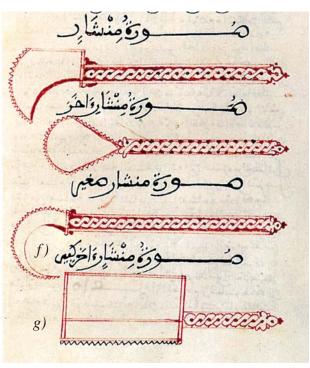
Notre modèle:
Laiton et acier inoxydable.
Longueur: 145 mm.
(Inventaire no. H 3.17)

Our model is based on the sketch drawn by L. Leclerc[13] after the illustrations in the Paris manuscripts of the *Taṣrīf* by az-Zahrāwī (4th/10th cent.). It corresponds to the drawing in the Oxford manuscript Marsh[14].

Albucasis. On Surgery and Instruments, p. 567 (MS Marsh).

az-Zahrāwī, *Taṣrīf*, MS Veliyeddin no. 2491, fol. 185a.

[11] *La chirurgie d'Abulcasis*, p. 219, fig. no. 128.
[12] No. 2491, fol. 185b.; v. also E. Gurlt, *Geschichte der Chirurgie,* vol. 1, p. 642 and plate V, no. 81; K. Sudhoff, *Beiträge zur Geschichte der Chirurgie im Mittelalter*, 2nd part, p. 58 (repr., op. cit. p. 208).
[13] *La chirurgie d'Abulcasis*, p. 218, fig. no. 119.
[14] Bodleian Library, Marsh 54, v. *Albucasis. On Surgery and Instruments*, p. 567; v. also E. Gurlt, *Geschichte der Chirurgie,* vol. 1, p. 642 and plate V, no. 79.

g)

‹Large hacksaw›

(*minšār kabīr*)

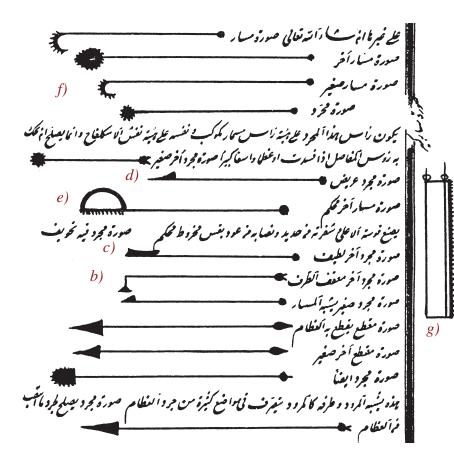
Our model:
Brass and stainless steel.
Length: 255 mm.
(Inventory No. H 3.18)

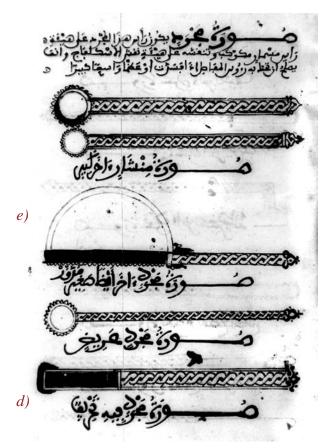
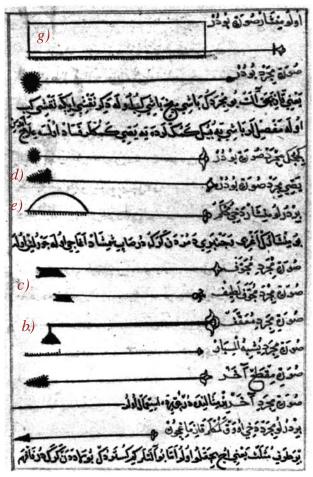
Our model is based on the sketch drawn by L. Leclerc[15] after the illustrations in the Paris manuscripts of the *Taṣrīf* by az-Zahrāwī (4th/10th cent.). Additionally, the illustrations from the manuscript Veliyeddin[16] at Istanbul and from one of the Paris manuscripts are reproduced here.[17]

az-Zahrāwī, *Taṣrīf*,
MS Veliyeddin no. 2491, fol. 145 b.

f)

g)

az-Zahrāwī, *Taṣrīf*,
MS Paris Bibl. nat. ar., 2953, fol. 79 b.

Early European saw for cutting bones (ca. 1550), Nuremberg, ‹Germanisches Nationalmuseum›.

[15] *La chirurgie d'Abulcasis*, p. 218, fig. no. 122; v. also E. Gurlt, *Geschichte der Chirurgie,* vol. 1, p. 642 and plate V, no. 80.
[16] No. 2491, fol. 145b.
[17] Bibl. nat., ar. 2953, fol. 79b.

In view of the fact that the following surgical instruments are depicted variously in different manuscripts, it seemed advisable to collect the relevant pages of the manuscripts here and to indicate with the letters of the alphabet those instruments which we reconstructed.

az-Zahrāwī, *Taṣrīf,* Süleymaniye Kütüphanesi, collection Beşirağa 502, facsimile ed., vol. 2, p. 528.

az-Zahrāwī, *Taṣrīf,* MS Paris Bibl. nat., ar. 2953, fol. 80.

From the Turkish version of az-Zahrāwī's text by Šerefeddīn (9th/15th cent.). MS Paris suppl. turc 693, fol. 138a.

az-Zahrāwī, *Taṣrīf*, MS Berlin, Staatsbibl., MS or. 91, f. 154a.

az-Zahrāwī, *Taṣrīf*, MS Veliyeddin no. 2491, fol. 185-186a.

I

VARIOUS INSTRUMENTS

from al-Fusṭāṭ (Egypt)

ca. 3rd/9th cent.?

(Originals in the Islamic Museum, Cairo)

Our models (figs. 1-5)
Brass, partly silver-plated
(Originals of copper alloys)
Length: 44-137 mm.
(Inventory nos. H 8.01-43)

The few publications[1] to have appeared so far on these uncertain archaeological finds do not, unfortunately, offer the detailed comparison needed for their identification with instruments known from literature; in some cases, the function is obvious, e.g. tweezers (fig. 1, on the right); others are unusual but can be identified quite correctly with the help of the descriptions and illustrations in the *Kitāb at-Taṣrīf*; e.g. fig. 1, 2 from the left is probably a multiple cauter (see above, pp. 60, 81) which would be useful for eyelids; a few more common cauters of the kind described in az-Zahrāwī's book (see above, p. 36 ff.) are collected in fig. 5; fig. 4 shows two classical forms of the scalpel.

[1] Sami K. Hamarneh, *Excavated Surgical Instruments from old Cairo, Egypt,* in: Annali Dell'Istituto e Museo di Storia della Scienza di Firenze, 2/1977/1–14, 6 fig.

2

3

4

5

Chapter 8

Chemistry and Alchemy

An occidental idealised portrait of Geber, the Latinised name of Ǧābir b. Ḥaiyān (2nd/8th cent.), the father of Arab chemistry. The picture is from Codex lat. Ashburnham 1166 of the Biblioteca Laurenziana at Florence[1]; the scroll on the side reads: «Deus et natura non faciunt frustra».

[1] v. G.B. Hartlaub, *Der Stein der Weisen*, Munich 1959, pl. 15; E.E. Ploss, H. Roosen-Runge, H. Schipperges and H. Buntz, *Alchimia. Ideologie und Technologie*, Munich 1970, p. 84; H. Schipperges, *Arabische Medizin im lateinischen Mittelalter*, p. 135.

Introduction

When we trace the origin of the words chemistry and alchemy back a long way through the occidental cultural sphere, we encounter in about the 12th century the Arabic loanword *kīmiyāʾ* or, with its article, *al-kīmiyāʾ*. Prpbably we strike here on the word χυμεία, χημεία or κημία that had been used by the Greeks since an unknown time, a word whose origin the philologists and historians of chemistry have not yet agreed on.[1] Chemistry or alchemy in the sense of the transmutation or imitation of metals, or the art of making gold, under the name of *al-kīmiyāʾ*, reached the Arabic-Islamic culture area rather early, in any case earlier than the *ʿilm aṣ-ṣanʿa*, which we encounter since the middle of the 2nd/8th century in the works of the most important figure of Arab alchemy, Ǧābir b. Ḥaiyān, in the sense of the art of the quantitative transformation of materials on a qualitative basis.[2]

That the inhabitants of the Arabian peninsula possessed a rather sound knowledge of metallurgy and of the manufacture of glass before Islam has been attested by the rich finds unearthed since 1971 at the excavations of Qaryat al-Fau.[3] The answer to the question of how far this knowledge had spread in Arabia will be one of the tasks which future historians of science will have to solve. We shall not indulge in any guesswork about the question of whether this knowledge was accompanied by some type of written documents.

The earliest preoccupation by Muslims with chemistry-alchemy as a scientific discipline is connected in Arabic literature with the names of scholars from the conquered territories. According to several early Arabic sources, Prince Ḫālid b. Yazīd, a son of the second Umaiyad ruler (d. probably after 102/720), was the first among the Arabs to preoccupy himself with this art. He himself states that having missed the caliphate he turned to scientific studies, particularly to alchemy.[4] He is said to have been the first to suggest the translation of books on astronomy, medicine and alchemy.[5] Among his teachers in alchemy are named a Stephanos and a Marianus of Alexandria.[6] The grounds for his position in the history of Arab alchemy agree with one another in the treatises preserved under his name, in the statements of several Arabic sources and in the relevant citations and references in alchemical literature.

Moreover, there is the evidence of several extant manuscripts on books that were translated from the Greek into Arabic on his orders. Of course, not all scholars share the conviction expressed here.

The doubts concerning the role assigned to Ḫālid b. Yazīd in the history of alchemy go back to a scholar who otherwise made a significant contribution to the study of Arabic-Islamic science, namely to Julius Ruska,[7] who, however, almost categorically denied the beginning of the study of this and other scientific [**98**] disciplines in Islamic times

[1] v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 4, Leiden 1971, p. 3; see also E. E. Ploss, H. Roosen-Runge, H. Schipperges, H. Buntz, *Alchimia. Ideologie und Technologie*, Munich 1970, p. 15.

[2] v. F. Sezgin, op. cit., vol. 4, pp. 4-10.

[3] The place lies 700 km south-west of ar-Riyāḍ in today's Saudi Arabia. At present I have only the first of the volumes on the excavations to have appeared so far: *Qaryat al-Fau. A Portrait of Pre-Islamic Civilisation in Saudi Arabia* by A. R. al-Ansary, Riyadh 1982.

[4] v. Ibn an-Nadīm, *Fihrist*, p. 354; F. Sezgin, op. cit., vol. 4, p. 121.

[5] F. Sezgin, op. cit., vol. 4, p. 121.

[6] ibid, p. 122.

[7] I do not wish to miss the opportunity to make available to future research a note I made (in the margin of p. 124) in my own copy of the 4th volume of the *Geschichte des arabischen Schrifttums* about one of the objections raised by Ruska. It is a response to H. E. Stapleton and R. F. Azo, *An Alchemical Compilation of the Thirteenth Century, A. D.*, in: Memoirs of the Asiatic Society of Bengal (Calcutta) 3/1910-1914/57-94, especially. p. 60 (repr. in: Natural Sciences in Islam, vol. 61, Frankfurt 2001, pp. 27-64, esp. p. 30). This involves the statement made by Ḫālid b. Yazīd in his *Risāla fi ṣ-Ṣanʿa aš-šarīfa wa-ḫawāṣṣihā*, where in connection with some medicine he says that he had treated Ṭalḥa b. ʿUbaidallāh with it. Stapleton and Azo take this name to be that of the war-hero of the same name who fell in 656 A.D. in the so-called camel battle, before Ḫālid b. Yazīd was born, and conclude from this that the treatise is a fake. Ruska seized the opportunity to agree with this. (*Arabische Alchemisten. I. Chālid ibn Jazīd ibn Muʿāwiya*, Heidelberg 1924, p. 29; repr. in: Natural Sciences in Islam, vol. 59, Frankfurt 2001, p. 29). Apart from my response that other persons by the name Talḥa b. ʿAbdallāh (or ʿUbaidallāh) known to the sources could come into question here, I find the note that in the manuscript Nuruosmaniye 3633 (fol. 172 b) the statement of Ḫālid runs like this: *ʿālağtu Ibn Abī ʿUbaidallāh* («I have treated Ibn Abī ʿUbaidallāh»).

before the 3rd/9th century. Ruska did not, as far as I know, deal with the pseudepigrapha—which appear in Arabic literature as titles, in quotations or as extant works, and the question of whose historicity is of great importance not only for the history of Arab chemistry-alchemy, but for the history of chemistry-alchemy as such—as one of the fundamental problems in the emergence of Arabic-Islamic knowledge, but discussed them from case to case and almost always considered them as writings authored by the «Arabs» themselves. However, if that were so, then in the field of alchemy—and not only there—the «Arabs» would be in an unusual situation of having authored their sources under pseudonyms in order to be able to quote them later as such in their own works. The question that logically follows from this, namely, whether in terms of content the Arabs could actually have been the authors of these pseudepigraphical sources at all has not, as far as I know, been seriously asked yet. Many share Ruska's attitude.

In most of the volumes of my *Geschichte des arabischen Schrifttums*, published since 1967, I have clearly stated the ideas about this problem that occurred to me in the course of my work on the history of Arabic-Islamic sciences. Naturally, I am not happy that my ideas have not found the acceptance which I expected from most of the colleagues in the field. However, nowhere do I find my views refuted with well-founded arguments.

Within the narrow confines of this introduction I wish to say just this: the writings on alchemy preserved in Arabic literature which pretend to be works by the authorities of Antiquity or which are in circulation as translations under unknown names are, in my view, important documents for a period that is still too little known in the history of the subject. By this is meant the period of Late Antiquity when pseudepigraphy enjoyed great popularity. Its beginnings among the Greeks extend back to the second century B.C. The pseudepigrapha bring us into contact with an aspect of science that was cultivated originally by the ancient Egyptians and the Greeks, and which was later cultivated in the cultural centres along the Mediterranean in Late Antiquity until the time of Early Islam, and was enriched with new elements and ideas; these were not necessarily correct in all cases, but through these the disciplines concerned seem to have reached quite a high standard.

Not all treatises on alchemy preserved in Arabic translation belong to the realm of pseudepigrapha. Among the true original which are extant only in Arabic translation, we must count, e.g. several works by Zosimus from Upper Egypt (fiourished probably between 350 and 420 A.D.). His main work, *Muṣḥaf aṣ-ṣuwar*,[8] which was discovered by the author of these lines, is probably the most important extant document of the alchemy of Late Antiquity. Future studies of this book will certainly lead to a new understanding of the history of alchemy in Late Antiquity.[9]

Incidentally, not all the originals of the pseudepigrapha preserved in Arabic translation are lost. The extant corpus of original texts in the field of alchemy and beyond, consisting both of independent books and also of fragments in Arabic literature, should in fact suffice for ruling the «Arabs» out as the authors of the pseudepigrapha. The conventional manner of looking at things stems from a period of research in the history of chemistry and alchemy, when practically nothing was known about the relevant Arabic material, and should therefore be reconsidered critically. The materials [**99**] put together in the fourth volume of the *Geschichte des arabischen Schrifttums* could provide impetus for such a reconsideration in accordance with the present state of knowledge.

Alchemical pseudepigrapha began reaching the Arab-Islamic world in the first century of Islam (7th cent. A.D), perhaps already together with some works which carried the names of their true authors. Persons who were acquainted with these writings and could communicate and translate their contents were as a rule members of the cultural elite of the conquered countries which, along with their cultural centres, were now part of the Islamic territory. With the translation of those works and the supported continuation of practical alchemical art by the old representatives and their newly found pupils the period of the reception of the subject in the

[8] F. Sezgin, op. cit., vol. 4, p. 75.

[9] Regrettably, an Arabist, displaying much destructive energy, took the liberty, in his handbook, which appeared soon after the fourth volume of the Geschichte des arabischen Schrifttums, of referring to the book *Muṣḥaf aṣ-ṣuwar* as «Letters from Zosimus to Theosebeia», parts of which consisted of fragments which I had listed as independent writings by Zosimus. He pronounced this judgment from his desk, without having seen any of the works mentioned.

Arabic-Islamic culture area began. The content of these writings originating in these new circles could, understandably enough, consist for quite some time of nothing but imitations and adaptations of the earliest translated works which had been authored by the youngest representatives of the discipline from the old cultural centres. The intensity of the continuation of chemistry-alchemy, the greatly enhanced interest in the subject and the helpful support on behalf of the neighboring disciplines which had found their way into the new cultural sphere at about the same time made possible a rapid transition to the phase of assimilation and shortly afterwards even to creativity. The content of those earliest translations and the quotations of Arab alchemists from them create the impression that the art of alchemy must have reached by and large a remarkable level among the people living along the Eastern Mediterranean shortly before the advent of Islam. The main thing that was lacking was exchange and interaction between the traditional cultural centres. That situation changed in the early Islamic period. Especially, Iraq with all its favourable conditions became the focal point. A phenomenon like Ǧābir b. Ḥaiyān, who combined in his work, appearing since about the middle of the 2nd/8th century, the two phases of the assimilation and creativity of Arabic alchemy which we have mentioned, can be explained only through this historic constellation. The chronological sequence of the progress of his thought which can be deduced from his works, the method of his citations and his attitude towards the sources help us to follow his development as clearly as with nearly no other comparable figure in intellectual history. The period of the history of alchemy which began with him, which was moulded by him and which enjoyed a comparatively high standard, was to extend up to the emergence of scholars like Boyle, Priestley and Lavoisier. His persona and his work embody almost singly the following period of the subject until the 11th/17th century in the Arabic-Islamic culture area and in the Occident. Therefore we wish to pay special attention to him at this point.

Ǧābir b. Ḥaiyān

In the fourth volume of my *Geschichte des arabischen Schrifttums* (pp. 132-269) which appeared in 1971, I treated the life and work of Ǧābir b. Ḥaiyān extensively and defended the authenticity of his lifespan and the corpus of his writings against the views of Paul Kraus, who from 1931 onwards upheld the view that Ǧābir was a legendary person and that the writings attributed to him were authored by representatives of the Ismaili school of alchemy in the period between circa 250/860 and 350/960. Leaving aside the strange dating, which is untenable in my view, Kraus showed in his book *Jābir ibn Ḥayyān. Contribution à l'histoire des idées scientifiques dans l'Islam*[10] in which he defends his idea of the origin of the corpus that the importance of the writings was unexpectedly great. The passage of time did not change my view of Ǧābir's lifespan and his authorship. Moreover, with the more comprehensive overview which I have gained through my work on other Arabic-Islamic sciences since 1971, I can relate the appearance of Ǧābir's writings only to his early date, in accordance with the Arabic sources. The author of those writings cannot have lived earlier or later than the second half of the 2nd/8th century.

Ǧābir was primarily an alchemist or rather a chemist. In the course of time and as a consequence of his becoming acquainted with translated works, his interest widened to include medicine, physics, astronomy, mathematics [**100**] and almost all other branches of knowledge of his time.

On the question of the historicity of Ǧābir and the authenticity of his work, Kraus himself provided us with important clues. Among these is the fact that many of the titles of Ǧābir's works mentioned by the historian of science Ibn an-Nadīm (4th/10th cent.) are corroborated by extant writings[11] and that there are cross-references between the titles,[12] thus confirming the chronological sequence of the works given by Ibn an-Nadīm after Ǧābir's own lists.[13]

The remarkable uniformity and consistency of the

[10] Vol. I: *Le corpus des écrits jābiriens*, vol. II: *Jābir et la science grecque*, Cairo 1942-1943 (repr. in: Natural Sciences in Islam, vol. 67-68, Frankfurt 2002).

[11] P. Kraus, *Jābir ibn Ḥayyān*, vol. 1, Introduction, p. 21; F. Sezgin, op. cit., vol. 4, p. 136.

[12] P. Kraus, op. cit., vol. 1, Introduction, pp. 24-25.

[13] ibid, vol. 1, p. 23.

ideas spread over various books and the bibliographical references, together with the frequent repetitions, help the dominant ideas in Ǧābir's system to stand out again and again.[14] In his first study on Ǧābir, Kraus[15] already noticed that Ǧābir's writings were characterised by certain common features of style and language. One could «therefore not take out an individual work from this corpus and declare it as unauthentic without endangering the authenticity of the entire collection.»[16] And: «All the individual features of the natural sciences are built into a larger context and receive their significance and justification only from this context. We are dealing here with a philosophical train of thought which is the actual starting point of the author and his strength throughout. Again and again he emphasises that the use of the equipment and the practice of science (*ʿamal*) leads nowhere if theory (*ʿilm*, *qijās*, *burhān*) is not given its proper place.»[17]

One of the characteristics of Ǧābir's alchemy is his notion that the elixir can be gained not only from mineral substances but also from animals and plants. He even favours the elixir from animal substances since these are more highly developed than the others.[18]

The extraction of the true elixir must rest on secure principles and must fulfil all the conditions of exactitude. For this Ǧābir relies on the idea that in the material world all things are composed of four elements which, for their part, are built up on four elementary qualities. Through the method of the proportions of equilibrium it is possible to define the shares of the four natures occurring in each body and to specify thus exactly its composition. The chemist will be able to control all changes that occur in the body as soon as he is able to produce separately each of the elements and elementary qualities through which nature operates. He will also be in a position to create on his own new bodies and, above all, various elixirs which are capable of acting upon the metals.[19]

Ǧābir describes the function of an elixir in the following manner: «The four principles which have an effect on the bodies from the three realms of nature, which infiuence them and determine their colour, are fire, water, air and earth. In fact there is no action in the three realms of nature which is not the result of these four elements. That is the reason why we rely in this art (of alchemy) on the treatment of these elements by strengthening those among them which are too weak and making weaker those which are too strong, in short, by upgrading that which is inadequate. He who succeeds in handling those four elements in the three realms of nature will thus achieve all that is to be known and will have a grasp of the knowledge of creation and of the art of nature.»[20]

For the distillation of organic substances, Ǧābir reserves an important place the kind of which cannot be found in the same measure in the earlier development of [**101**] this science. What is remarkable about it is, above all, the use of sal ammoniac not only of inorganic substances but also of organic ones. Because of their volatility, he counts sal ammoniac together with sulphur, mercury and arsenic among the so-called «spirits».[21]

The characteristic features of his chemistry also include the clear description of procedures and apparatuses, the methodological classification of substances, emphasis on the experiment as an important component, and a theory which is conclusive in itself.[22]

Guided by his trust in human reason and natural law, Ǧābir poses the question of artificial procreation (*taulīd*). «For him any living creature, in fact even humanity itself, is the result of the forces of nature working together. For, nature, in its crea-

[14] P. Kraus, op. cit., vol. 2, p. 135; F. Sezgin, op. cit., vol. 4, p. 137.

[15] *Dschābir ibn Ḥajjān und die Ismāʿīlijja*, in: Forschungsinstitut für Geschichte der Naturwissenschaften in Berlin. Dritter Jahresbericht. Mit einer wissenschaftlichen Beilage: *Der Zusammenbruch der Dschābir-Legende*. Berlin 1930, pp. 23-42, esp. p. 24 (repr. in: Natural Sciences in Islam, vol. 70, Frankfurt 2002, pp. 97-116, esp. p. 98).

[16] ibid, p. 24 (repr., p. 98).

[17] ibid, p. 25 (repr., p. 99); F. Sezgin, op. cit., vol. 4, p. 137.

[18] P. Kraus, *Jābir ibn Ḥayyān*, op. cit., vol. 2, p. 3.

[19] P. Kraus, op. cit., vol. 2, pp. 4-5; F. Sezgin, op. cit., vol. 4, p. 138.

[20] Ǧābir, *Kitāb as-Sabʿīn*, facsimile ed. under the title *The Book of Seventy*, Frankfurt, Institut für Geschichte der Arabisch-Islamischen Wissenschaften 1986, pp. 266-267; *Muḫtār rasāʾil Ǧābir b. Ḥaiyān*, ed. by P. Kraus, Cairo 1935 (repr. Natural Sciences in Islam, vol. 66, Frankfurt 2002), p. 481; transl. by P. Kraus, *Jābir ibn Ḥayyān*, op. cit., vol. 2, p. 7; F. Sezgin, op. cit., vol. 4, pp. 138-139.

[21] F. Sezgin, op. cit., vol. 4, p. 140; cf. P. Krause, *Jābir ibn Ḥayyān*, op. cit., vol. 2, p. 41.

[22] cf. P. Kraus, op. cit., vol. 2, p. 32; F. Sezgin, op. cit., vol. 4, p. 140.

tions, obeys a law of quantity and numbers, the secret of which is unveiled through the theory of the proportions of equilibrium. The imitation of the procedure of nature, indeed its improvement when necessary, is possible—at least theoretically.»[23]

The idea of human automatons (homunculus) occupied the Middle Ages and the Renaissance, but rarely does the problem get such scientific treatment and rarely is it discussed in such detail as done by Ǧābir.

The essential features of Ǧābir's system include measuring the four natures and establishing the quantity with which they are represented in each individual body. If the proportions can be defined exactly, it will also be possible to alter the composition of bodies through additions to or subtractions of their natures and to thus create new bodies.[24]

Within the framework of his theory, Ǧābir compares the non-material natures with dots or zeroes. The four natures that constitute the principle of the elements can be grasped only through intellect. Their warmth and dryness are not perceivable; that is why they act as the zero does to numbers. Zero does not possess any numerical value just as natures can neither be felt nor seen.[25]

His belief in the mathematical order of the material world and in the possibility of explaining the qualitative change of substances on a quantitative basis is most clearly expressed in his theory of the proportions of equilibrium which he calls *ʿilm al-mīzān*. This, in Ǧābir's view, is «the fact that the specific characteristics (*ḫawāṣṣ*) of substances, particularly in the field of chemistry, can be measured and are based on numerically ascertainable proportions. If, e.g., vinegar loses its acidic taste when litharge is added, it means that vinegar had at first a specific composition which can be expressed in numbers and that this was altered through the addition of litharge which can likewise be expressed numerically. The appearance of the specific characteristic, in this case the capability of litharge to alter vinegar, is therefore not accidental but depends on the inner composition of the matter, and to alter this at will is the task of the chemical procedure (*tadbīr*). If the specific characteristics have a mathematical rationale, then the procedure also has its justification and its correctness is—according to Dschābir—established.»

«Thus the principle of the measurability of bodies (*mīzān*) implies that everything in the cosmos conforms to mathematical laws. It indicates the rational order of things, their harmony. On the one hand, it is manifest in each and every thing, even in the smallest, on the other, it is the broad abstract concept of our world. *Mīzān* is the symbol for world order. Provided that there can be only one mathematical rationale of the specific characteristics, provided that it is clear in itself and cannot be described now in one way and now in another, in short, that there is only one type of *mīzān*, only one highest world principle .»[26]

From his basic chemical-physical notions, Ǧābir is led to the formulation of [**102**] another system which he calls *ʿilm al-ḫawāṣṣ* («science of the specific characteristics»). Here he deals with the peculiarities of minerals, plants and animals, their «sympathies» and «antipathies» and with the significance of their characteristics for the technical and medical field.[27] With his immense material «Ǧābir is not satisfied with a simple order or classification of the characteristics. As strange as they might seem, they must be submitted to a rational explanation, otherwise they cannot be the subject of an exact science. Beyond empirical observation, which itself aims to establish even unusual characteristics of natural things, one must define the causes on which they depend.»

«In his *Kitāb al-Ḫawāṣṣ*, Ǧābir frequently connects the concept of the characteristics with that of the cause (*ʿilla*, *sabab*). He criticises not only those theologians (*ahl aš-šarʿ*) who deny the existence of the characteristics, but also the philosophers—among them Aristotle in particular—who maintain that the cause of the characteristics is beyond human understanding.»[28]

[23] cf. P. Kraus, op. cit., vol. 2, p. 32; F. Sezgin, op. cit., vol. 4, p. 141.

[24] cf. P. Kraus, op. cit., vol. 2, p. 32; F. Sezgin, op. cit., vol. 4, p. 145.

[25] P. Kraus, op. cit., vol. 2, pp. 179-181; F. Sezgin, op. cit., vol. 4, p. 145.

[26] P. Kraus, *Dschābir ibn Ḥajjān und die Ismāʿīlijja*, op. cit., pp. 25-26 (repr., op. cit., pp. 99-100); F. Sezgin, op. cit., vol. 4, pp. 145-146.

[27] P. Kraus, *Jābir ibn Ḥayyān*, op. cit., vol. 2, p. 91; F. Sezgin, op. cit., vol. 4, p. 140.

[28] P. Kraus, *Jābir ibn Ḥayyān*, op. cit., vol. 2, p. 94; F. Sezgin, op. cit., vol. 4, p. 140.

«… Ǧābir attempts to find a causal explanation of the causes.»[29] «Convinced that he developed natural sciences on the basis of strict exactitude, Ǧābir is bold enough to believe that he has wrested the very last secret from nature. The characteristic feature of his science consists in no admitting any limit for human thought.»[30]

These are just a few of the concepts of chemistry-alchemy and the natural sciences excerpted from Ǧābir's writings by Paul Kraus, which I selected and cited in order to give the reader a general impression. Ǧābir left behind a very extensive corpus of writings as can be judged from the self-citations and the cross-references, from the lists of titles preserved in literature and from his extant works. Kraus attempted to record as completely as possible the manuscripts available in the libraries at his time. Today the extent of the preserved writings known to us is considerably larger than the titles recorded by Kraus.[31] Moreover, Kraus was not able to study all the writings of Ǧābir, but did manage a relatively large part. All the same, his remarks on the ideas hidden in those manuscripts are enough to show that we are dealing with one of the most interesting and most original figures in the history of science and that those treatises reflect individual steps in the rapid and continuous development of a scientist who wishes to learn everything, who advances what he has learnt and who incorporates it continuously anew into a scientific system of natural philosophy. The vast body of knowledge that Ǧābir was able to acquire and assimilate in the course of more than fifty years in that 2nd/8th century when various works from foreign cultures, particularly from the Greeks, became accessible to Muslims through translations led Kraus, unfortunately, to an erroneous conclusion. He thought that being convinced of the authenticity of Ǧābir's corpus would mean setting up at the beginning of Arabic science a personality who would have anticipated the entire achievements of the following generations and made them superfluous.[32] Here we must contradict Kraus unreservedly. As wide as the framework of Ǧābir's universal knowledge might have been, as masterly and as original the ideas expressed in his works may appear, we still miss in his writings the distinctive achievements known to us at this period of Arabic-Islamic science of the 3rd/9th century and the following centuries. Perhaps we can come closer to a true assessment of his actual position in the history of science [**103**] when we imagine that he created a synthesis on the basis of the individual pieces of knowledge that had become known to him through the pseudepigrapha and the original writings of preceding generations and through the notions which he developed on the basis of his own experiences—a synthesis which we may call the foundation of chemistry-alchemy as a science based on experiment and theory. The development achieved by him was so enormous that it slowed down afterwards in the Islamic world, but without coming to a full stop. Its direct and indirect influence on the origin and development of the subject in the Occident extends, according to the present state of our knowledge, from the 13th up to the 17th century, when efforts began to be made in the West to place the subject on a new basis.

The art of alchemy-chemistry was extensively cultivated among Ǧābir's contemporaries and in the first two generations following him. Of the importance of the titles known to us through citations and of the few extant treatises, no evaluation is available which rests on an examination of this material. The natural philosopher Yaʿqūb b. Isḥāq al-Kindī[33] (d. soon after 256/870) seems to have taken a rather negative attitude towards *al-kīmiyāʾ*. Of course, today, we are not yet in a position to determine what exactly he rejected[34] in chemistry-alchemy, which gave his younger contemporary Abū Bakr ar-Rāzī a cause for refutation (*Kitāb ar-Radd ʿala l-Kindī fī raddihī ʿala ṣ-ṣināʿa*). Al-Kindī's extant *Kitāb fī Kīmiyāʾ al-ʿiṭr wa-t-taṣʿīdāt*[35] («Book on the chemistry of perfumes and distillations») allows us to suppose that he rejected the notion of transmu-

[29] P. Kraus, *Jābir ibn Ḥayyān*, op. cit., vol. 2, p. 95; F. Sezgin, op. cit., vol. 4, p. 141.

[30] P. Kraus, *Jābir ibn Ḥayyān* op. cit., vol. 2, pp. 98-99; F. Sezgin, op. cit., vol. 4, p. 141.

[31] v. F. Sezgin, op. cit., vol. 4, pp. 231-269. In Tripoli (Libya) in 1980 I happened to come across an important anthology with about forty until then mostly unknown treatises by Ǧābir. I have a low-quality Xerox-copy of the manuscript which is mislaid at present.

[32] P. Kraus, *Jābir ibn Ḥayyān*, vol. 1, Preface, p. 48; F. Sezgin, op. cit., vol. 4, pp. 184, 189.

[33] v. F. Sezgin, op. cit., vol. 3, pp. 244-247.

[34] v. ibid, vol. 4, p.6.

[35] ed. and transl. into German by Karl Garbers, Leipzig 1948 (repr. Natural Sciences in Islam, vol. 72, Frankfurt 2002).

tation and the corresponding imitations. This book consists of a collection of more than one hundred recipes «for the manufacture of fragrant oils and ointments as well as aromatic waters, and for the substitution or rather the counterfeiting of precious drugs, which give an interesting insight into the perfumery and also the trade in drugs and perfumes of those times».[36] The eminent physician and philosopher Abū Bakr Muḥammad b. Zakarīyāʾ ar-Rāzī[37] (b. ca. 251/865, d. 313/925) was seriously engaged in the art of chemistry-alchemy. Apart from the fact that he refers to Ǧābir in his fundamental work on alchemy, the *Kitāb al-Asrār*,[38] ar-Rāzī is highly dependent on Ǧābir as shown clearly by H. E. Stapleton,[39] R. F. Azo and M. Hidāyat Ḥusain in 1927 through a comparison between the works of Ǧābir and ar-Rāzī which were available to them. Our knowledge of ar-Rāzī's chemistry-alchemy is due for the most part to Julius Ruska, whose investigations, translations and editions of ar-Rāzī's texts between 1928 and 1939 filled a considerable lacuna in the history of chemistry. He calls ar-Rāzī «the pioneer of chemistry» or even «the founder of a new chemistry». He came, however, to this conclusion because he accepted P. Kraus's view that Ǧābir was a fictitious figure.

From ar-Rāzī's propaedeutic introduction (*Kitāb al-Mudḫal at-taʿlīmī*), Ruska[40] communicates the manner in which he introduces instruments: «According to Rāzī, each art has its special instruments … Thus alchemy also uses instruments and substances that must be known very thoroughly when wanting to deal with this art. First, the 'bodies' [*ağsād*] and the 'spirits' [*arwāḥ*], i.e. the metals and the volatile substances, sulphur, mercury, zarnīch and sal ammoniac must be known, then the different kinds of salts, borax, vitriol and alum, then certain ores and rocks and some substances which are produced artificially. Again, the construction and function of the apparatuses used for melting the metals and the treatment of other substances must be known, that is to say, the kilns, hearths, crucibles, distillation fiasks and other utensils. An apparatus for sublimation is already discussed in great detail here, which is called *al-uṯāl* in Arabic [**104**] and which is known even now under that name 'aludel'. After studying the substances and the apparatuses, the pupil should then proceed to the study of the behaviour of the substances under different procedures.»

Since Ruska[41] failed to recognise Ǧābir's historicity, he was convinced that ar-Rāzī should get the credit «for having brought alchemy into a strictly scientific form for the first time.» For the sake of comparison between the two great figures in the history of alchemy-chemistry, Ǧābir and ar-Rāzī, I reiterate here my conviction which I voiced 31 years ago: while Ǧābir, in his purely alchemical treatises, draws upon a manifold system of ideas for the experiments and observations and while he again and again stands out as a great and independent natural philosopher, it is characteristic of ar-Rāzī to create with short instructions and brief descriptions of the materials, apparatuses and procedures an alchemy-chemistry which has to serve more practical purposes.[42] As I see it, the chemistry-alchemy we know from the works of ar-Rāzī would be unthinkable without the great opus of Ǧābir which preceded it.

Like Ǧābir's writings, ar-Rāzī's also exercised a great infiuence on the process of dealing with chemistry and its progress up to a new stage of development in the 17th century in the Occident (see below, p. 105 ff.). It is one of the conspicuous phenomena of the history of alchemy that a contemporary of ar-Rāzī named Abū ʿAbdallāh Muḥammad Ibn Umail,[43] ignoring the progress made by the experimental scientific method of the subject, continued on a path of alchemy that operated with allegories. J. Ruska thought that he had found the home of this allegorical orientation in Egypt. Without thinking of a specific home, we believe that the origin of this orientation of alchemy is to be sought in

[36] Karl Garbers, op. cit., p. 2.
[37] v. F. Sezgin, op. cit., vol. 3, pp. 274-294; vol. 4, pp. 275-282.
[38] v. ibid, vol. 4, pp. 216-217.
[39] *Chemistry in Iraq and Persia in the tenth century A. D.*, in: Memoirs of the Asiatic Society of Bengal 8/1922-29/317-418, esp. pp. 335-340 (repr. in: Natural Sciences in Islam, vol. 73, Frankfurt 2002, pp. 9-114, esp. pp. 27-32).
[40] *Al-Rāzī's Buch Geheimnis der Geheimnisse. Mit Einleitung und Erläuterungen in deutscher Übersetzung*, in: Quellen und Studien zur Geschichte der Naturwissenschaften und der Medizin, vol. 6, Berlin 1937, p. 10 (repr. in: Natural Sciences in Islam, vol. 74, Frankfurt 2002, pp. 1-260, esp. p. 24).
[41] *Al-Rāzī's Buch Geheimnis der Geheimnisse*, op. cit., p. 13 (repr., op. cit., p. 27).
[42] F. Sezgin, op. cit., vol. 4, p. 277.
[43] ibid, vol. 4, pp. 283-288.

the pre-Islamic pseudepigrapha, which include the *Turba Philosophorum*[44] (before the 4th cent. A.D.).[45] Ibn Umail seems to have found a rather wide popularity in the Occident. The Latin allegorists called him Senior Zadith filius Hamuelis.

Chemistry-alchemy, widely propagated by Ǧābir and ar-Rāzī, continued to be cultivated for centuries in the Arabic-Islamic culture area. However, we do not know of any scholar among their successors who had made his mark by developing the field further on a new creative basis, a field which had been shaped by Ǧābir and ar-Rāzī. The work done by the following generations consists of relatively modest contributions in which the progress achieved was not so much in the realm of theory but in practical application, such as, e.g., the widespread use of saltpeter or the quite advanced development of inks. Thus H. E. Stapleton and R. F. Azo found in the small treatise by Abu l-Ḥakīm Muḥammad b. ʿAbdalmalik al-Kāṯī[46] (written 426/1035) chemical procedures, as one would find again only 700 years later in the writings of J. Black and A.-L. Lavoisier.[47] Unfortunately, research is in rather poor shape, especially in this area of Arabic-Islamic chemistry-alchemy.

After this overview I would like to discuss briefiy the question of the continuation of Arabic-Islamic alchemy in the Occident. The beginnings of the knowledge of Arabic chemistry-alchemy in the Latin world continue to remain a mystery. At this point we have no reason for believing that in this field, too, Arabic treatises came to the knowledge of Europeans through translations as early as in the 4th/10th century. But on the other hand, we know for certain that Arabs in Spain could already author books on this subject in the first half of the 5th/11th century.[48] In this connection it is worth noting that the historian of chemistry, Marcelin Berthelot, could ascertain towards the end of the 19th century that in the second edition of the famous treatise *Mappae clavicula* (on the production of colours and dyeing) some Arabic alchemistic [**105**] terms occur.[49] These and other elements, missing in the older of the two extant manuscripts of the treatise, which probably dates from the 10th century, led to the assumption that they were interpolated in the first half of the 12th century. This edition, which also contains some English words, is even associated with the name of the famous English scholar and translator Adelard of Bath.[50] Based on this fact, the historian of chemistry, John Maxson Stillman[51] opined: «It is during the twelfth century that Christian Europe first seems to have assimilated the results of Arabian chemistry and it is probable that these manuscripts had their origin either in Italy or in the south of France.» Once sufficient insight into the translated material from Arabic alchemical-chemical books, their adaptations, imitations and forgeries in Latin literature, has been gained it is possible to reach the supposition that the beginnings of the translation activity in this area can be placed in the first half of the 12th century. Julius Ruska[52] asked himself in 1935 how the Occident got to know these books. His answer which, as I believe, is still valid even now is as follows: «For the time being it is difficult to say what the circumstances were on which the selection of the translated authors depended. We can hardly credit the oldest translators with a special knowledge of the field and critical acumen. Thus they would have been dependent on the judgment of the Muslims to whom they owe the Arabic material; in other words, the oldest stock of Latin alchemy must have been a refiection of the literature which enjoyed wider popularity and special esteem in the Islamic west in the 11th/12th century.»

Even now we are far removed from even an approximate idea as to which and how many treatises altogether of Arabic-Islamic alchemy reached the Occident in translations. Several treatises under the

[44] F. Sezgin, op. cit., vol. 4, pp. 60-66.

[45] ibid, p. 286.

[46] ibid, p. 291-292.

[47] H. E. Stapleton, R. F. Azo, *Alchemical equipment in the eleventh century A. D.*, in: Memoirs of the Asiatic Society of Bengal 1/1905/47-70, part. p. 48 (repr. in: Natural Sciences in Islam, vol. 61, Frankfurt 2001, p. 2).

[48] F. Sezgin, op. cit., vol. 4, pp. 294-298.

[49] *La chimie au moyen âge*, vol. 1, Paris 1893 (repr. Osnabrück, Amsterdam 1967), p. 59.

[50] G. Sarton, *Introduction to the History of Science*, vol. 1, pp. 533-534; E. E. Ploss, H. Roosen-Runge, H. Schipperges, H. Buntz, Alchimia, op. cit., p. 52 ff.

[51] The Story of Alchemy and Early Chemistry, New York 1960 (repr. of The Story of Early Chemistry, New York 1924), p. 188.

[52] *Übersetzung und Bearbeitungen von al-Rāzīs Buch Geheimnis der Geheimnisse*, in: Quellen und Studien zur Geschichte der Naturwissenschaften und der Medizin, vol. 4, Berlin 1935, pp. 153-239, esp. p. 154 (repr. in: Natural Sciences in Islam, vol. 74, Frankfurt 2002, pp. 261-347, esp. p. 262).

authorship of Geber and Rhazes (ar-Rāzī) had been widely circulated since at least the 13th century. Historians of chemistry of the 18th and 19th centuries identified the former with Ǧābir b. Ḥaiyān. The most vehement objection to this identification came in 1893 from the French historian of chemistry M. Berthelot.[53] In his opinion «the Arabic works of Dschābir, judged by the accuracy in the presentation of facts, as also by the clarity of the teachings and the literary structure, are infinitely far removed from the Latin treatises of the pseudo-Gerber. Not only is any knowledge of the new and original facts contained in these Latin treatises missing in the writings of the Arabic author, but it is not even possible to find in them even a single page or paragraph that could be considered a translation from the Arabic works.» Here Berthelot refers to the following Geber-treatises 1. *Summa perfectionis magisterii*; 2. *De investigatione perfectionis*; 3. *De inventione veritatis*; 4. *Testamentum Geberi*.
Julius Ruska[54] was perhaps the first Arabist to deal with the Geber question, even though at a time (1929) when just very few Arabic manuscripts of Ǧābir's were known. On the content of the treatises, Ruska says:[55] «In order to move one step ahead with the Geber problem we must take note of three things: the general dependence of the Geber treatises on Arabic alchemy, the special dependence on Dschābir, and the new experiences and observations [**106**] which are set down in these treatises. That the author is dependent on Arabic alchemy in all the essentials is obvious. I consider it totally impossible that his work could be the translation of a work by the old Dschābir ibn Ḥajjān. In which respect the author already goes beyond the Arabs cannot be ascertained today when we consider that we still have only an unsatisfactory grasp of Arabic alchemy today.» About the author Ruska says:[56]
«That the author of the Geber treatises was a person who knew Arabic alchemy very well is obvious at every step. Certain sentences and expressions, even complete chapters, can perhaps be shown to have been used in Arabic alchemical treatises as well [here he refers to the Arabic proverb 'haste is of the devil' which appears in *De investigatione perfectionis*]. But I do not believe that the '*Pseudo-Geber*' had Arabic originals in front of him and that he translated from them …».
«So far all attempts to throw light on the darkness surrounding the personality of the author of the Geber treatises have been in vain. His Latin schooling points to his being a cleric familiar with matters related to the natural sciences.»
During his intensive study of Abū Bakr ar-Rāzī's chemistry-alchemy, Ruska was led, in the fourth decade of the 20th century, to an explanation of the authorship of *The Summa Perfectionis magisterii* which he then considered as basically settled.[57] The crucial factor was a piece of information in the manuscript of the Latin version of ar-Rāzī's «Mystery of Mysteries» which is preserved in the Riccardiana library in Florence.[58] There Ruska found the author's indication that he wanted to write another book entitled *Summa* on all questions of alchemy.[59] Of course, it is not at all safe to equate this *Summa* with *The Summa Perfectionis magisterii*, for the Latin translator could have rendered any one of the three Arabic terms *ǧāmiʿ*, *ḥāwī* or *maǧmūʿ* with the word summa, assuming that the adaptation was done by a person who wrote in Arabic. Ruska noticed further that in this codex ar-Rāzī's book shows signs of an adaptation. He wondered whether it was an Arabic adaptation of the *Kitāb Sirr al-asrār*, which could have been done for instance in Spain or whether it was a late Latin adaptation. «The occasional use of the Arabic formulas, cum Deo, nutu Dei, Deo volente etc., in any case no longer suffices for the assumption of a translation after an Arabic original. The consistently better form of the Latin sentence structure and the entire

[53] *La chimie au moyen âge*, vol. 3, Paris 1893 (repr. in: Natural Sciences in Islam, vol. 64, Frankfurt 2002), p. 23; J. Ruska, *Die bisherigen Versuche, das Dschâbir-Problem zu lösen*, in: Forschungs-Institut für Geschichte der Naturwissenschaften in Berlin. Dritter Jahresbericht, Berlin 1930, p. 14 (repr. in: Natural Sciences in Islam, vol. 70, Frankfurt 2002, pp. 89-102, esp. p. 94); F. Sezgin, op. cit., vol. 4, p. 175.
[54] *Pseudo-Geber*, in: Das Buch der großen Chemiker, ed. Günther Bugge, vol. 1, Berlin 1929, pp. 32-41 (repr. in: Natural Sciences in Islam, vol. 70, Frankfurt 2002, pp. 72-81). Here Ruska depends on the German translation of the Geber treatises by Ernst Darmstaedter, *Die Alchemie des Geber*, Berlin 1922.
[55] *Pseudo-Geber*, op. cit., p. 66 (repr., op. cit., p. 78).
[56] *Pseudo-Geber*, op. cit., pp. 40-41 (repr., op. cit., pp. 80-81).
[57] *Al-Rāzī's Buch Geheimnis der Geheimnisse … in deutscher Übersetzung*, op. cit., p. 33 (repr., op. cit., p. 47).
[58] J. Ruska, *Übersetzung und Bearbeitung von al-Rāzīs Buch Geheimnis der Geheimnisse*, op. cit., p. 178 ff. (repr., op. cit., p. 286 ff).
[59] ibid, p. 238 (repr., op. cit., p. 346).

construction of the chapters seem to indicate an original Latin composition. But in particular … the references to later paragraphs in the large overall plan of the work, which are not contained in the *k. sirr alasrār*, testify to the achievement of a Christian alchemist, an achievement that was independent in form and presentation, though dependent on Arabic sources.»[60]

I find it difficult to understand how Ruska, to whom the history of Arabic chemistry-alchemy owes so much, could reach an explanation in which he declared «the references to later paragraphs» occurring in a 13th century manuscript[61] of the Latin version of the *Sirr al-asrār* by ar-Rāzī as the achievement of a Latin alchemist, which this person was supposed to have achieved in dependence on Arabic sources. Ruska does not state whether this (Christian) alchemist who wrote in Latin was also supposed to have been the translator of the original work, or whether he, on the basis of some knowledge of Arabic sources, merely «revised»[62] the book that had been translated by somebody else. However, it is especially remarkable that Ruska noticed that, among the Arabic sources of the book, the 38th chapter of the «Seventy Books» (*al-Kutub as-sabʿūn*) by Ǧābir bears the title «Book of Games» (*Kitāb al-Laʿba*[63]), Latin *Liber ludorum*.[64] Here it is important for us to see that, judging from the quality of the excerpts, [**107**] these go back directly to the Arabic original and are not borrowed from the highly corrupt Latin translation *Liber de septuaginta*[65], which had been in circulation in Europe possibly since the 12th century. This is supported by the fact that the additions also include the plate with the chemical instruments (see below, p. 110), whose Arabic names the translator had to accept frequently because of the absence of Latin equivalents.

On another occasion, Ruska[66] offers a substantially different but rather helpful explanation for the origin of this Latin adaptation of Rāzī's *Sirr al-asrār*: «The evidence which I produced to show that a complete Latin translation of this work [*Sirr al-asrār*] is available in an old manuscript in Palermo permits the conclusion that it was translated for the first time in Sicily. But it also reached Spain and underwent numerous adaptations in which the descriptions of the materials and the instruments were increasingly expanded. An excellent example of such treatises derived from al Rāzī is the work *De Alumnibus et Salibus*, edited here, which was authored by a Spanish alchemist of the 11th/12th century and was already available in a Latin translation at the beginning of the 13th century.»

It becomes clear, not only[67] from this statement, that Ruska presupposes an activity of Spanish-Arabic alchemists in the 5th/11th to 6th/12th centuries, thus showing the historian the way to a solution in his endeavour to explain the origin of the Geber treatises and also of other Latin alchemical texts of the 13th and 14th century.

Without intending to dwell any longer on the discussion of this question, I would like to say that I consider not only the *Secretum Bubacaris* (*Sirr al-asrār* by ar-Rāzī) but also the Latin Geber treatises as translations of adaptations which had originated for their part in the Arabic-Islamic world (such as in Spain or Northern Africa), incorporating the latest developments. This type of adaptation, while retaining the original author's name, is known to us from almost all fields of Arabic-Islamic sciences. If those treatises show, for instance, the knowledge of saltpetre, then this goes back to the fact that, besides the earlier knowledge, saltpetre was widely known in the 12th century. It may also be mentioned that Geber's Summa perfectionis contains long passages from Ǧābir's *Kitāb as-Sabʿīn*, which turn out to be

[60] J. Ruska, op. cit., pp. 205-206 (repr., op. cit., p. 313 ff).
[61] ibid, op. cit., p. 178 (repr., op. cit., p. 286).
[62] ibid, op. cit., 212 (repr., op. cit., p. 320).
[63] F. Sezgin, op. cit., vol. 4, p. 242.
[64] J. Ruska, *Übersetzung und Bearbeitungen von al-Rāzīs Buch Geheimnis der Geheimnisse*, op. cit., p. 212 ff. (repr., op. cit., p. 320 ff.).
[65] cf. ibid, p. 215 (repr., op. cit., p. 323).
[66] *Das Buch der Alaune und Salze. Ein Grundwerk der spätlateinischen Alchemie*, edited, translated and explained, Berlin 1935, p. 12 (repr. in: Natural Sciences in Islam, vol. 73, Frankfurt 2002, pp. 227-351, esp. p. 236).
[67] cf. also J. Ruska, *Über die Quellen des Liber Claritatis*, in: Archeion (Rome) 16/1934/145-167, esp. p. 166 (repr. in: Natural Sciences in Islam, vol. 71, pp. 431-453, esp. p. 452) where he says: «In a still unpublished book I have furnished proof that this treatise does not belong to Rāzī but must have been authored by a Spanish Moor in the 11th/12th century.»

independent of its Latin translation *Liber de septuaginta*.
Starting out from Ruska's work, W. R. Newman has dealt, repeatedly since 1985, with the question of the identity of the Latin writings of Geber.[68] For their explanation he consulted the treatise *Theorica et practica* of an almost unknown Paulus de Tarento, who was probably a Franciscan from the Assisi cloister. Newman established that the *Theorica et practica* contains, in parts verbatim, some passages from the adaptation of ar-Rāzī's *Secretum* as available in the Riccardiana manuscript at Florence (which he calls *De investigatione perfectionis*). In view of Ruska's remark that the author of the adaptation of the *Secretum* announces that he himself intends to write a *Summa*, Newman concludes that Paulus de Tarento is the author of *The Summa Perfectionis magisterii*.[69] Newman attempts to support his theory with many reasons and arguments. At least he tries, in one passage as far as I see, to point out that such a theory by the very nature cannot claim absolute [**108**] certainty.[70] Even though we cannot say that we agree with his conclusion, yet we must acknowledge with gratitude that he gave us access to rich alchemical materials in the Latin language. Moreover, he was the first to show that the author of *The Summa Perfectionis* bases his work, to a large extent, upon Ǧābir's «Seventy Books».[71] He has shown that Ǧābir's *Kitāb al-Uṣūl* is preserved in Latin translation under the name of *Liber radicum Rasis de alkimia*.[72]
In his main work and also in several articles, Newman treats the question of the impact of *The Summa Perfectionis*. Since, in his opinion, the book was written by Paulus de Tarento between the last quarter of the 13th century and the beginnings of the 14th century[73], he comes to the conclusion that the alchemical works of the 13th century which used the Summa as a source are preudo-treatises. These include books like the Semita recta by Albertus Magnus,[74] the Tres epistolae by Roger Bacon[75] and also the Rosarium by Arnaldus Villanovanus.[76]
In order not to stretch the framework of this introduction too far, I shall just mention the question of the dissemination of the true or false writings of Rhazes (Abū Bakr ar-Rāzī),[77] Avicenna (Ibn Sīnā,[78] Senior Zadith (Ibn Umail),[79] and the writings that came into circulation as early as in the 13th century under the name of Raimundus Lullus[80] (ca. 1232-ca. 1316) to whom many texts of Arabic provenance or later forgeries were attributed.
Latin alchemical literature provides us with an instructive example of the entire process of the period of reception and assimilation of the Arabic-Islamic sciences. Individual questions like the Geber problem can, I believe, be solved more easily when they are treated within this broad framework of the period of adaptation that lasted, with certain deviations, from the 10th until the 15th and in some areas also up to the 16th century.
Let this introduction be concluded with a clarification by Julius Ruska[81] regarding the sources of Latin alchemy, which he voiced 67 years ago and

[68] *New Light on the Identity of «Geber»,* in: Sudhoffs Archiv [69]/1985/76-90; idem, *The Genesis of The Summa Perfectionis*, in: Archives internationales d'histoire des sciences (Paris) 35/1985/240-302; idem, *The Summa Perfectionis of Pseudo-Geber. A Critical Edition, Translation and Study*, Leiden 1991; idem, *L'influence de la Summa perfectionis du Pseudo-Geber*, in: J.-C. Margolin, S. Matton (Eds.), *Alchimie et philosophie à la Renaissance*, Paris 1993, pp. 65-77.
[69] W. R. Newman, *The Summa Perfectionis*, op. cit., p. 64 ff.
[70] W. R. Newman, *The Summa Perfectionis*, op. cit., p. 102.
[71] However, in my opinion, not on the Latin translation.
[72] W. Newman, *An unknown Latin translation of Jābir*, in: Archives internationales d'histoire des sciences 35/1985/301-302.
[73] *The Summa Perfectionis*, op. cit., p. 208.
[74] W. Newman, The Genesis of *The Summa Perfectionis*, op. cit., pp. 246-259; idem, *The Summa Perfectionis*, op. cit., pp. 193-194.
[75] W. Newman, *The Alchemy of Roger Bacon and the Tres Epistolae Attributed to him*, in: Comprendre et maîtriser la nature au Moyen Âge. Mélanges d'histoire des sciences offerts à Guy Beaujouan, Paris 1994, pp. 461-479.
[76] *The Summa Perfectionis*, op. cit., pp. 193-208.
[77] J. Ruska, *Pseudepigraphe Rasis-Schriften*, in: Osiris (Bruges) 7/1939/31-94 (repr. in: Natural Sciences in Islam, vol. 73, Frankfurt 2002, pp. 353-416).
[78] J. Ruska, *Die Alchemie des Avicenna*, in: Isis (Bruges) 21/1934/14-51 (repr. in: Natural Sciences in Islam, vol. 60, Frankfurt 2001, pp. 244-281); idem, *Avicennas Verhältnis zur Alchemie*, in: Fortschritte der Medizin (Berlin) 52/1934/836-837 (repr. in: Natural Sciences in Islam, vol. 60, pp. 242-243); G. C. Anawati, *Avicenne et l'alchimie*, in: Convegno Internazionale, 9-15 Aprile 1969. Tema: Oriente e Occidente nel medioevo: Filosofia e scienze, Roma 1971, pp. 285-346; F. Sezgin, op. cit., vol. 4, pp. 8-9.
[79] Studies on Ibn Umail and his impact are collected in Natural Sciences in Islam, vol. 75, Frankfurt 2002.
[80] *Alchimia. Ideologie und Technologie*, op. cit., p. 72; M. Pereira, *The Alchemical Corpus attributed to Raymund Lull*, London: The Warburg Institute 1989.
[81] *Übersetzung und Bearbeitungen von al-Rāzī's Buch*, op. cit., p. 153 (repr., op. cit., p. 261).

which, in my opinion, is still fully justified: «It cannot be emphasised strongly enough that the alchemy of the Latin West owes practically nothing to the Greeks and nearly everything to the Arabs. For decades we stared at the fragments of the works of the Greek alchemists as if we could explain from these the content and the nature of Latin alchemy; and meanwhile we neglected the most obvious task of tracing the occidental literature first of all to its direct and immediate sources. It is not the Greek alchemists but the translations of Arabic original works that constitute the basis of Latin alchemy, and again and again it is the translations and adaptations of Arabic authors that determined the course of developments in the Occident.»

I

Chemical Laboratory Equipment

The science-historical fact that the art of chemistry cultivated before the advent of Islam in Mediterranean and neighbouring cultures was not limited merely to theoretical knowledge but also included apparatuses for practical use is, for me, beyond any doubt. However, the question of since when the members of the new cultural sphere, Muslims and non-Muslims, had begun working with those apparatuses is still uncertain. Unlike most specialists in this field, the writer of these lines believes that the beginning of the use of laboratory equipment in the field of chemistry-alchemy can be traced back to as early as the first century of Islam (7th century A.D.).

Unfortunately, very little has been preserved of such tools and apparatuses that were prepared in the new culture area of Islam, at first as imitations of those of the preceding cultures, which then were advanced or invented afresh. Leaving aside smaller accessories like spatulas and tongs (see below, vol. V, 141 ff.), the archaeological finds unearthed so far are merely the fragments of larger apparatuses. But a study that aims to assess the relevant material in the museums of the world still awaits to be seen. The extant equipment known to us includes propulsion hammers (*māšiq*), plate shears (*miqṭaʿ*), tongs or tweezers (*māsik*), mortars (*hāwūn*), casting spoons (*miġrafa*), casting moulds (*rāṭ* or *misbaka*), bottles (*qārūra*, pl. *qawārīr*), phials (*qinnīna*, pl. *qanānī*), jugs (*kūz*, pl. *kīzān*), distillation caps (*inbīq*, *anbīq*, pl. *anābīq*), «gourds», i.e. retorts (*qarʿa*, pl. *qaraʿ*, Latin *cucurbita*) and receptacles (*qābila*, pl. *qawābil*).

Of the studies on the chemical apparatuses in the Arabic-Islamic culture area, we may mention the following:

Rubens Duval, *Traité d'alchimie syriaque et arabe*. II. *Traduction du texte arabe*, in: M. Berthelot, *La chimie au moyen âge*, vol. 2, Paris 1893 (repr. Osnabrück 1967), pp. 141-165.

H. E. Stapleton, R. F. Azo, *Alchemical equipment in the eleventh century, A. D.*, in: Memoirs of the Asiatic Society of Bengal 1/1905/47-71. Here the relevant sections from the *ʿAin aṣ-ṣanʿa wa-ʿaun aṣ-ṣanaʿa* by Abu l-Ḥakīm Muḥammad b. ʿAbdalmalik al-Ḫwārizmī al-Kāṯī[1] have been edited and translated into English.

Eilhard Wiedemann, *Über chemische Apparate bei den Arabern*, in: *Beiträge aus der Geschichte der Chemie*, dem Gedächtnis von Georg W. A. Kahlbaum, ed. by Paul Diergart, Leipzig and Vienna 1909, pp. 234-252 (repr. in: Wiedemann, *Gesammelte Schriften*, vol. 1, pp. 291-309): German translation of the relevant chapters from the *Kitāb al-Asrār* by Abū Bakr ar-Rāzī, *Mafātīḥ al-ʿulūm* by Abū ʿAbdallāh al-Ḫwārizmī, the list from *Kitāb al-Muḫtār fī kašf al-asrār* by ʿAbdarraḥmān b. ʿUmar al-Ǧaubarī and the explanations by Abū ʿAbdallāh Šamsaddīn ad-Dimašqī.

H. E. Stapleton, R. F. Azo, M. Hidāyat Ḥusain, *Chemistry in ʿIrāq and Persia in the tenth century A. D.*, in: Memoirs of the Asiatic Society of Bengal 8/1928/318-417.

J. Ruska, *Übersetzung und Bearbeitungen von al-Rāzī's Buch Geheimnis der Geheimnisse*, in: Quellen und Studien zur Geschichte der Naturwissenschaften und der Medizin (Berlin) 4/1935/153-239, esp. pp. 230-237.

J. Ruska, *al-Rāzī's Buch Geheimnis der Geheimnisse mit Einleitung und Erläuterungen in deutscher Übersetzung*, in: Quellen und Studien zur Geschichte der Naturwissenschaften und der Medizin (Berlin) 6/1937/1-246, esp. pp. 54-63, 92-99.

Ahmad Y. al-Hassan, Donald R. Hill, *Islamic technology. An illustrated history*. Cambridge etc. 1986, p. 193 ff.

Unfortunately, the extant Arabic manuscripts on chemistry and alchemy very rarely include illustrations of the apparatus. The oldest known drawings are to be found in the *Kitāb Kīmiyāʾ al-ʿiṭr wa-t-tasʿīdāt* by Yaʿqūb b. Isḥāq al-Kindī (d. soon after 256/870), in a manuscript dating from 405/1014.[2] Illustrations are also occasionally found in medical or cosmographical works or in books on

[1] v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 4, Leiden 1971, pp. 291-292.

[2] v. ibid, vol. 3, Leiden 1970, p. 246; translated by Karl Garbers, Leipzig 1948, pp. 93-95, Arabic text pp. 49-51.

military technology. [**110**] The situation regarding the description and classification of apparatuses is much more favourable. Thus, for instance, the physician and chemist Abū Bakr ar-Rāzī[3] (d. 313/925) describes in his *Sirr al-asrār*, 25 apparatuses,[4] divided according to the two functions of «melting of metals» and «treatment of non-metals». It is a stroke of good luck for the history of chemistry that a Latin manuscript, which through its title *Secretum Bubacaris* proclaims the authorship of Abū Bakr ar-Rāzī,[5] contains illustrations of 42 apparatuses. The deviations, errors and additions which occur in the Latin version when compared with the Arabic text led Julius Ruska to the assumption that the Latin version, despite much agreement with the Arabic text, was in fact an adaptation that may have originated in Spain. Be that as it may, the descriptions and names of the apparatuses we know from the Arabic original allow us to conclude that the illustrations in the Latin Riccardiana manuscript (Florence) are related to those in ar-Rāzī's original text. Another, less substantial, depiction of chemical apparatus from ar-Rāzī's book is contained in a manuscript of the Latin version in Bologna (university library 184, fol. 234) which was made known by Giovanni Carbonelli[6] in 1925. An important compilation of illustrations of chemical furnaces, as we encounter occasionally in Arabic sources or in the Latin tradition of Arabic chemistry-alchemy such as in the Geber treatises, is contained in a manuscript of the *Liber florum Geberti*. This treatise was published by W. Ganzenmüller[7] in 1942. Nothing is known so far about any Gebert; most likely it is a misspelling of Geber. Ganzenmüller considers it «a rather clumsily chosen pseudonym».[8] Of Arabic authors, Gebert mentions ar-Rāzī (Albuchasir) and Ibn Sīnā (Avicenna). «As far as the content of the alchemical observations is concerned, the procedures mentioned in the foreword come, in the final analysis, from Razi's *Secretum Secretorum* …»[9] Ganzenmüller points out one special feature of the *Liber florum*, namely that «the numerous illustrations and their designations» are marked «not with words, numbers or letters, but with strange symbols which are not met with otherwise in alchemical writings.»[10] This reminds us of the symbols used by Abu l-ʿIzz Ismāʿīl b. ar-Razzāz al-Ǧazarī (ca. 600/1200) in his al-*Ǧāmiʿ bain al-ʿilm wa-l-ʿamal* for labelling the parts of the depicted apparatuses, and these may lead us to traces of a possible Arabic prototype. In any case, Ganzenmüller recognises in many of the illustrations «quite clearly a Moorish style».[11] We are therefore justified in introducing to the public, within the scope of the apparatuses and devices of Arabic-Islamic chemistry-alchemy known to us, models of a selection of the furnaces illustrated in the *Liber florum Geberti* as well.

[3] v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 3, p. 274 ff., vol. 4, p. 275 ff.

[4] v. J. Ruska, *Al-Rāzī's Buch Geheimnis der Geheimnisse*, op. cit., pp. 92-99 (repr., op. cit., pp. 106-113).

[5] v. J. Ruska, *Übersetzung und Bearbeitungen von al-Rāzī's Buch*, op. cit., p. 83 (repr., op. cit., p. 343).

[6] *Sulle fonti storiche della chimica e dell' alchimia in Italia*, Rome 1925, p. 110.

[7] *Liber Florum Geberti. Alchemistische Öfen und Geräte in einer Handschrift des 15. Jahrhunderts*, in: Quellen und Studien zur Geschichte der Naturwissenschaften und der Technik (Berlin) 8/1942/273-304 (repr. in: Natural Sciences in Islam, vol. 63).

[8] ibid, p. 288.

[9] ibid, p. 291.

[10] ibid, p. 294.

[11] ibid, p. 295.

[111] Apparatus
for the Distillation of Rose-water
described by az-Zahrāwī

The Andalusian physician Abu l-Qāsim Ḫalaf b. ʿAbbās az-Zahrāwī[1] (late 4th/10th cent.) deals rather extensively with the distillation of rose-water in the third paragraph of the 28th chapter of his *Kitāb at-Taṣrīf li-man ʿağiza ʿan at-taṣnīf*.[2] He says that the procedure for the distillation of rose-water was known to many people. He mentions it here, as he says, for two reasons. First, because it is relevant to the topic of the paragraph in question (on medicines made from animal substances) and second, to teach those who otherwise do not find a teacher. He knows four processes: 1. with water and wood fire, 2. with water and coal fire, 3. with wood fire and without water, 4. with coal fire and without water. The first is the most commonly used. After pointing out the differences in the quality of products made by the four processes, he describes first an apparatus used in Iraq for the extraction of rose-water for the rulers, and then the process common in Andalusia. While describing this, he omits certain details which he obviously expects his readers to know. For instance, we are not told how the receptacles were fastened or suspended.

The Iraqi method places a large vessel (*ṣihrīğ*) in an expansive room. The base and sides of this vessel are made of lead and are watertight. It should be closed with a firm lid. Into the lid should be cut as many holes as required by the number and size of the intended retorts (*buṭūn*): fifty, one hundred or two hundred. Then a large copper cauldron in the form of a boiler for bath water should be taken. It [as the water reservoir] should be fastened behind the wall, above the vessel which is on the stove. It must be assured that the smoke of the stove is directed to the outside so that the rose-water is not affected by it. Then the water [from the cauldron] should be allowed to run into the vessel on the stove … The retorts should be placed in the holes and the spaces in between should be sealed well by using strips of linen. If the retorts are not of glass, they can be of glazed earthenware. This also applies to the receptacles into which the distilled rose-water drips.

After this, az-Zahrāwī briefiy describes the process common in Andalusia which, as a matter of fact, hardly differs from the method used in Iraq. az-Zahrāwī's description, which seems to be incomplete, at least in the manuscript available to me, reached the Occident at the latest in a separate Latin translation of the 28th chapter. This translation called *Liber servitoris de praeparatione medicinarum* [**112**] *simplicium* appears to have been made

Our model:
Copper and wood, laminated.
6 alembics of glass.
Total height 1.2 m.
(Inventory No. K 1.63)

[1] F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 3, Leiden 1970, pp. 323-325.

[2] Facsimile edition, Frankfurt, Institute for the History of Arabic-Islamic Sciences, 1986, 2 vols., esp. vol. 2, pp. 399-400.

through an intermediary Hebrew translation.[3] It is uncertain whether az-Zahrāwī also added illustrations to the description of the distillation vessels, as he did for surgical instruments. The explanation for the term Berchile appearing in the Latin translation has frequently occupied the attention of the experts.[4] It tended quite often to be regarded as the name of the apparatus itself. The term appears in the Arabic original in the sense of a «kettle of copper» (*qidr min nuḥās*). We encounter it in the Kitāb al-Asrār by Abū Bakr ar-Rāzī as a kettle with feet (*qidr .. ʿalā haiʿat al-mirǧal*).
Az-Zahrāwī's depiction of the distillation apparatus seems to have strongly infiuenced the professional circles in Europe, either through his description or through a possible illustration. In 1787 the Swedish scientist Torbern Bergman[5] called this description «one of the first and the best».
The innovations connected in the historiography of chemistry with az-Zahrāwī's description include the use of distillation retorts of glazed earthenware, apart from those of glass.[6] It is also possible that the shape of the retort with an enlarged head,[7] which was called «Moore's head» by European chemists of the 16th century, is connected with az-Zahrāwī's description. For, in the course of time, the shape of the retorts placed upon the holes in the lid of the distillation vessel, as az-Zahrāwī describes them, takes on a hybrid dimension.[8] The fact that az-Zahrāwī speaks in the same context also of the distillation of ethanol (ethyl alcohol) attracted the attention of some historians of chemistry.[9]
Our model was constructed after the description of the Arabic text, with the exception of the manner in which the receptacles are fastened. We kept the number of alembics at a relatively small number of six, which was chosen at random. According to az-Zahrāwī it can go up to 250.

Preliminary sketch of our model.

[3] M. Steinschneider, *Die hebräischen Übersetzungen des Mittelalters und die Juden als Dolmetscher*, Berlin 1893 (repr. Graz 1956), p. 740; F. Sezgin, Introduction to the facsimile edition of the *Kitāb at-Taṣrīf*, op. cit., pp. 5-6.
[4] M. Berthelot, *La chimie au moyen âge*, Paris 1893 (repr. Osnabrück 1967), vol. 1, pp. 139-141; H. Schelenz, *Zur Geschichte der pharmazeutisch-chemischen Destilliergeräte*, Miltitz 1911 (repr. Hildesheim 1964), pp. 34-35; E. O. von Lippmann, *Beiträge zur Geschichte der Naturwissenschaften und der Technik*, Berlin 1923, p. 78, note 2; M. Speter, *Zur Geschichte der Wasserbad-Destillation: Das «Berchile» Albukasims*, in: Pharmaceutica Acta Helvetica (Amsterdam) 5/1930/116-120 (repr. Natural Sciences in Islam, vol. 62, pp. 294-298); J. Ruska, *Über die von Abulqāsim az-Zuhrāwī* (read Zahrāwī) *beschriebene Apparatur zur Destillation des Rosenwassers*, in: Chemische Apparatur (Berlin) 24/1937/313-315 (repr. Natural Sciences in Islam, vol. 62, pp. 299-301).
[5] Historiae chemiae medium seu obscurum aevum, Leipzig 1787, p. 7; see E. Gildemeister, Fr. Hoffmann, *Die ätherischen Öle*, 2nd ed., Miltitz 1910, vol. 1, pp. 27-28.
[6] E. Gildemeister, Fr. Hoffmann, *Die ätherischen Öle*, op. cit., vol. 1, p. 218.
[7] v. ibid, p. 220; R. J. Forbes, *Short History of the Art of Distillation*, op. cit., pp. 83, 116, 140, 217.
[8] v. e.g. H. Brunschwig, *Das buch der waren kunst*, op. cit., fol. 41 b, 51 a, 134 a, 142 a, 217 a.
[9] H. Schelenz, *Zur Geschichte der pharmazeutisch-chemischen Destilliergeräte*, op. cit., p. 34; E. Gildemeister, Fr. Hoffmann, *Die ätherischen Öle*, op. cit., vol. 1, p. 220; E. O. von Lippmann, Beiträge zur Geschichte der Naturwissenschaften und der Technik, op. cit., p. 190; R. J. Forbes, *Short History of the Art of Destillation*, op. cit., p. 41.

Apparatus for distillation
from al-Mizza for extracting Rose-water

Our model (a)
Brass, acrylic and glass.
Height: 135 cm, diameter: 50 cm.
(Inventory No. K 1.01-2)

A large apparatus for extracting rose-water is described by the cosmographer Abū ʿAbdallāh Šamsaddīn Muḥammad b. Ibrāhīm b. Abī Ṭālib al-Anṣārī Šaiḫ ar-Rabwa (d. 727/1327), who is known to Arabists as ad-Dimašqī.[1] In the context of the topography of al-Mizza, a village near Damascus,[2] he describes this apparatus which appears to have been quite well known in the vicinity. The relevant text[3] was made accessible to the scholars by Eilhard Wiedemann through his essay Über chemische Apparate bei den Arabern, which appeared in 1909.[4] According to the description by «Dimasqi», the total height of the apparatus amounted to 1 1/2 times the height of a man. Even at the beginning of the 20th century a similar apparatus called karaka was in use in Syria.[5] The apparatuses at al-Mizza consisted of [**114**] several layers of retorts

[1] v. C. Brockelmann, *Geschichte der arabischen Litteratur*, vol. 2, p. 130; suppl.-vol. 2, p. 161.
[2] v. Yāqūt, *Muʿǧam al-buldān*, vol. 4, Leipzig 1869 (repr. Frankfurt 1994), p. 522.
[3] *Nuḫbat ad-dahr fī ʿaǧāʾib al-barr wa-l-baḥr*, ed. A. F. Mehren, St. Petersburg 1866 (repr. Frankfurt, Islamic Geography, vol. 203), pp. 194-195; French transl., idem, *Manuel de la cosmographie du moyen* âge, Copenhagen 1874 (repr. Frankfurt, Islamic Geography, vol. 204), p. 264.
[4] in: *Beiträge aus der Geschichte der Chemie*, dem Gedächtnis von Georg W. A. Kahlbaum, ed. by Paul Diergart, Leipzig and Vienna 1909, pp. 234-252, esp. pp. 245-249 (repr. in: Wiedemann, *Gesammelte Schriften*, vol. 1, pp. 291-309, esp. pp. 302-306); idem, *Zur Chemie bei den Arabern* (= Beiträge zur Geschichte der Naturwissenschaften XXIV), in: Sitzungsberichte der Physikalisch-medizinischen Sozietät (Erlangen) 43/1911/72-113, esp. pp. 107-112 (repr. in: Wiedemann, *Aufsätze*, vol. 1, pp. 689-730, esp. pp. 724-729).
[5] Wiedemann, *Über chemische Apparate*, op. cit., p. 245 (repr., p. 302); R. J. Forbes, *Short History of the Art of Distillation*, op. cit., pp. 48-52.

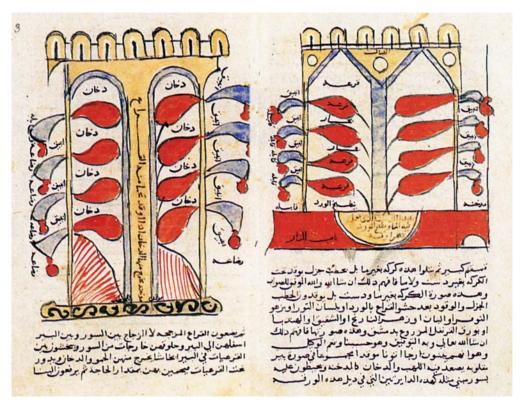



Fig. from ‹ad-Dimašqī›, *Nuḫbat ad-dahr*, MS Ayasofya 2945.

arranged in a radical manner with the openings to the outside. These retorts were filled with the petals to be distilled and were suspended in the smoke which started from a combustion chamber installed below and went up through a pervious shaft in the middle of the apparatus. The receptacles for the distilled liquid, which were joined to the retorts through «cap» and «beak», were fastened to the outer wall of the apparatus, which was completely covered at the top.

There seems to be a connection between this large distillation apparatus and the fornax rotunda of the Italian Pietro Andrea Mattioli[6] (1565), which looks like a beehive made of straw (fig. on the right).

This invalidates the judgment pronounced by Franz Maria Feldhaus[7] in 1914 to the effect that the Arabs did not know the distillation of rose oil.

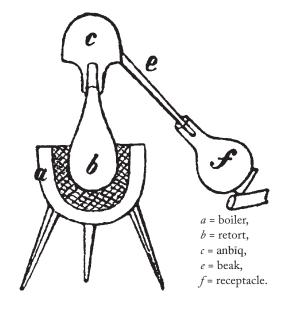
Fig. from Gildemeister/Hoffmann, *Ätherische Öle* (2nd ed., 1910), vol. 1, p. 232.

[6] *Opera quae extant omnia. Supplementum: De ratione destillandi aquas ex omnibus plantis et quomodo genuine odores in ipsis aquis conservari possint*. Basel 1565, p. 55 (not seen), see E. Gildemeister and Fr. Hoffmann, op. cit., vol. 1, pp. 231-232.
[7] *Die Technik. Ein Lexikon der Vorzeit* .., op. cit., p. 194.

Our model (b):
Brass and glass.
Total height 1.13 m.
(Inventory No. K 1.01-1)

The distillation apparatus from al-Mizza is represented in our museum by two reconstructed models. The smaller model, built in 1987 (above), displays a simpler representation which does not fully correspond with reality. The bottom right-hand corner has the opening for the fire; the combustion gases escape through the chimney. There is water in the inner basin, that evaporates as it is heated. The steam heats the rose petals in the retorts. Their distillate is collected in the outside receptacles.

Alembic

(latin *alembic*, Arabic *al-anbīq*) with beak and receptacle

Our model:
Clay, glass, stand
and copper boiler.
Total height: 77 cm.
(Inventory No. K 1.64)

Abū Bakr ar-Rāzī describes an advanced alembic: «The anbīq with a beak and its model are suitable for the distillation of liquids. The secret here is that the retort must be large and have thick walls, without any cracks at the bottom and without any bubbles in its wall, and that the anbīq must fit tightly and sit well. The boiler in which the anbīq is placed must have the shape of a cooking pot and the retort must be submerged in the water (of the boiler) up to the highest level of the substance contained in it. Moreover, near the furnace a large boiler with boiling water must stand so that water from it can be added to the boiler (of the water bath) when the water in the latter decreases. And care must be taken that the retort is not affected by cold water, and secure the retort so that it cannot move, its bottom does not touch the bottom of the boiler, lest it should burst.»[1]

Here we have the oldest description known to us of a distillation apparatus where the vapour condenses outside the cap in the receptacle. In 1909 E. Wiedemann[2] drew the following sketch (fig. on the right) after ar-Rāzī's description:

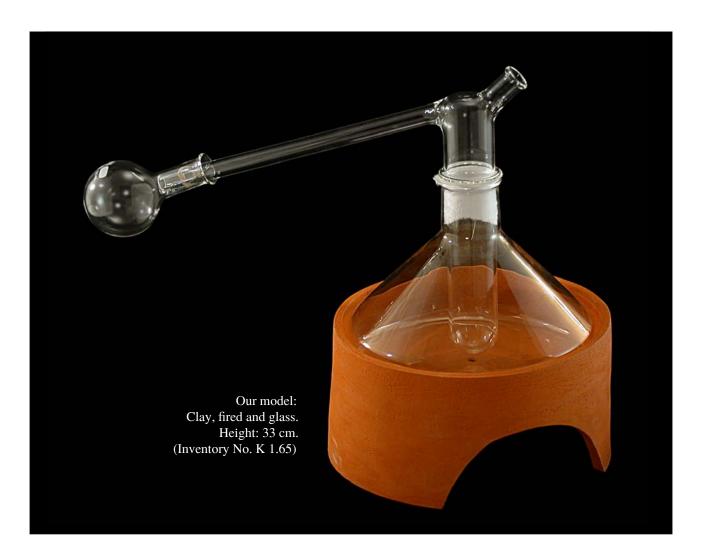



Fig. from Wiedemann, *Gesammelte Schriften*, vol. 1, p. 294.

a = boiler,
b = retort,
c = anbīq,
e = beak,
f = receptacle.

[1] *Kitāb al-Asrār wa-Sirr al-asrār*, ed. M. Taqī Dānišpažūh, Teheran 1964, p. 9; German translation J. Ruska, *Al-Rāzī's Buch Geheimnis der Geheimnisse*, Berlin 1937, p. 94.

[2] *Über chemische Apparate bei den Arabern*, op. cit., p. 237 (repr., p. 294).

Our model:
Clay, fired and glass.
Height: 33 cm.
(Inventory No. K 1.65)

Distillation Apparatus
whose retort is surrounded by steam

The cosmographer Šamsaddīn ad-Dimašqī (d. 727/1327) describes among the «apparatuses used by Greek and Arab chemists,» (*ālāt al-Yūnān wa-ahl al-ḥikma*) a distillation apparatus for rose-water called *az-zuǧāǧ al-ḥikmī*.[1] From this description it is evident that the retort in this device is surrounded by steam, i.e., there must be some distance between the inner base of the pot and the lower tip of the retort suspended in it.[2]

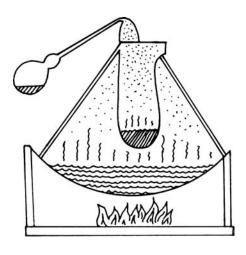
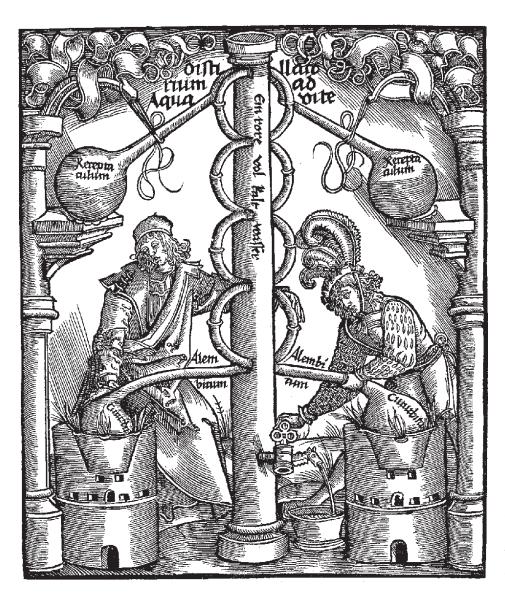



Fig. after ‹Dimašqī›, *Nuḫbat ad-dahr*.

[1] v. his *Kitāb Nuḫbat ad-dahr fī ʿaǧāʾib al-barr wa-l-baḥr*, op. cit., pp. 197-198, French transl., op. cit., p. 266.

[2] v. E. Wiedemann, *Über chemische Apparate*, op. cit., p. 248 (repr. in: *Gesammelte Schriften*, op. cit., vol. 1, p. 305

Apparatus
for the distillation of ethyl alcohol

Our model:
Brass and glass. Height: 160 cm.
Cooling tower with two retorts,
placed upon two furnaces.
Two glass containers on brass stands
at the end of the exchange pipe.
(Inventory No. K 1.02)

Gildemeister/
Hoffmann,
Die ätherischen Öle, 2nd ed.,
vol. 1, p. 45.

At the beginning of the 16th century[1] a distillation apparatus of enormous dimensions for the extraction of ethyl alcohol appeared in Central Europe. An illustration of it can be seen on the frontispiece of the *Liber de arte Distillandi de Compositis* by Hieronymus Brunschwig (ca. 1450- ca. 1512), which appeared in 1507. In its size and the purpose of construction, this apparatus combines in itself the characteristics of the large rose oil distillatory apparatus from al-Mizza (see above, p. 113) and of the ethyl alcohol distillatory apparatus by Abu l-Qāsim az-Zahrāwī (see above, p. 111). On the mutual relationship of these apparatuses, F. Gildemeister and Fr. Hoffmann state: «In the distillation of ethyl alcohol (*aqua vitae*), the method of cooling borrowed from the Arabs was considered the most perfect procedure and was chosen by Brunschwig as the cover picture for the second volume of his book on distillation which appeared in 1507, and this is reproduced on p. 45.»[2] (Illustration above).

«The connecting pipes (*serpentinae*) that proceed upwards in wavy curves between the two retorts (*curcubitae*) and receptacles (*receptacula*) pass, at their intersections, through a pipe filled with cold water.»[3]

[1] E. Gildemeister, Fr. Hoffmann, *Die ätherischen Öle*, 2nd ed., Leipzig 1910, vol. 1, pp. 42-47; R. J. Forbes, *Short History of the Art of Distillation*, Leiden 1948, pp. 117-120, 128-129.

[2] Gildemeister and Hoffmann, op. cit., p. 220.

[3] ibid, p. 220.

Our model:
Copper, tin-plated.
Height: 38 cm.
(Inventory No. K 1.66)

Alembic
for the extraction of ethereal oils and alcohol

Our Museum at the Institute possesses a specimen of the alembic made of copper; its shape goes back to the 6th/12th or the 7th/13th century. This apparatus is from Anatolia and comes from the collection of the pharmacologist Turhan Baytop (Istanbul). In this version the cooler lies directly above the pot which is heated.[1]

[1] Turhan Baytop, *Selçuklular devrinde Anadolu'da eczacılık*, in: 1. Uluslararası Türk-Islâm bilim ve teknoloji tarihi kongresi 14-18 eylül 1981 (Istanbul), Proceedings, vol. 1, pp. 183-192; idem, *Türk eczacılık tarihi*, Istanbul 1985, pp. 59-62.

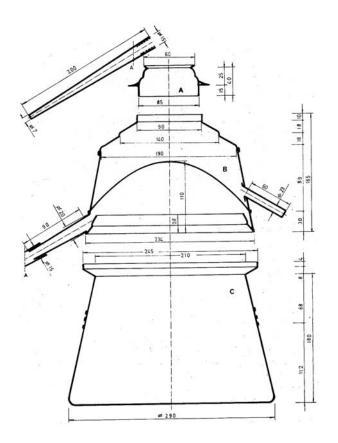
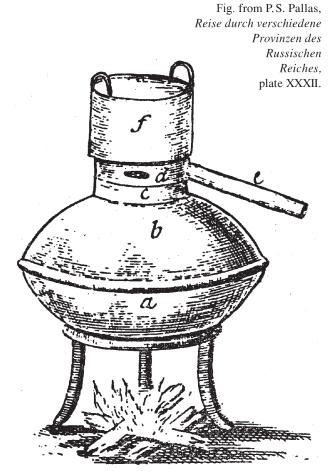
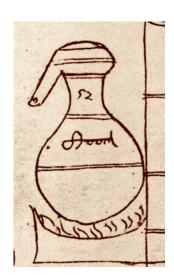
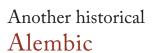



Fig. from T. Baytop, *Türk eczacılık tarihi*, op. cit., p. 62.

A: lead.
B: cooler.
C: pot.

Fig. from P.S. Pallas, *Reise durch verschiedene Provinzen des Russischen Reiches,* plate XXXII.

The previous owner, T. Baytop, is of the opinion that this type of alembic was commonly used by the Turks in Central Asia and Anatolia. Peter Simon Pallas,[2] the German explorer of Asia, noticed the use of a similar apparatus for the extraction of milk brandy in Central Asia between 1768 and 1774. He reproduced the apparatus in one of his plates of illustrations.[3]

[2] *Reisen durch verschiedene Provinzen des Russischen Reiches in den Jahren 1768-1774*, 3 vols.; St. Petersburg 1771-1774 (repr. Graz 1967), esp. vol. 3, p. 404; see T. Baytop, *Türk eczacılık tarih*, op. cit., pp. 53-54.
[3] Plate XXXII

Two alembics from the Munich manuscript of the *Liber florum Geberti* (cod. lat. 25110, nos. 37 and 52)

Another historical Alembic

in a simpler form, without cooling. Likewise from the collection of Turhan Baytop (Istanbul), now in the possession of the Institute.

Our model:
Copper, tin-plated.
Cap, removable
Height: 32 cm.
(Inventory No. K 1.67)

Our model:
Glass, in two parts.
Height: 105 mm.
(Inventory No. K 1.28)

Two figs. from: *Übersetzung und Bearbeitungen von al-Rāzī's Buch Geheimnis der Geheimnisse*, by Julius Ruska, op. cit., p. 235 (83).

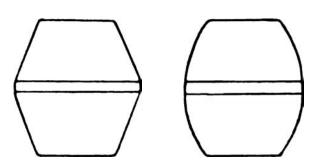
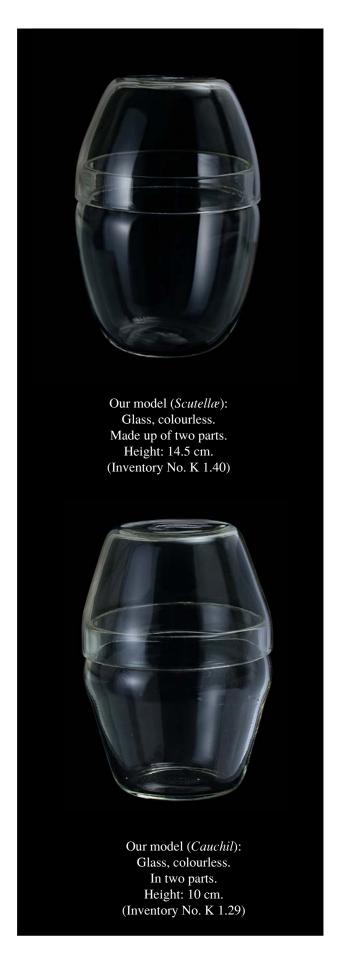
Our model:
Glass, colourless.
Height: 13 cm.
(Inventory No. K 1.32)

Apparatus

for the sublimation of dry substances

(Arabic *al-uṯāl*, Latin *alutel*, *aludel*)

According to Abū Bakr ar-Rāzī,[1] the *uṯāl* is used for the ‹sublimation› (*taṣʿīd*) of dry substances. Abū ʿAbdallāh Muḥammad b. Aḥmad al-Ḫwārizmī (2nd half of the 4th/10th cent.)[2] describes it as an apparatus made either of glass or clay.[3] Our model was made after the Latin translation[4] in which the name of the apparatus is given as alutel.

[1] *Kitāb al-Asrār wa-Sirr al-asrār*, op. cit., p. 10; J. Ruska, *Al-Rāzī's Buch*, op. cit., p. 97.
[2] v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 4, Leiden 1971, pp. 289-290.
[3] *Mafātīḥ al-ʿulūm*, ed. G. van Vloten, Leiden 1895 (repr. Leiden 1968), p. 257; German translation of the relevant chapter by E. Wiedemann, *Zur Chemie bei den Arabern*, op. cit., p. 78 (repr., p. 695).
[4] *Übersetzung und Bearbeitungen von al-Rāzī's Buch Geheimnis der Geheimnisse* by Julius Ruska, in: Quellen und Studien zur Geschichte der Naturwissenschaften und der Medizin (Berlin) 4/1935/153-239, esp. p. 235 (83).

[1] *Übersetzung und Bearbeitungen von al-Rāzī's Buch*, p. 234 (82).
[2] G. Carbonelli, *Sulle fonti storiche della Chimica e dell'Alchimia in Italia*, Rome 1925, p. 110.

Illustr. extraites de: *Übersetzung und Bearbeitungen von al-Rāzī's Buch Geheimnis der Geheimnisse* par Julius Ruska, p. 235 (83).

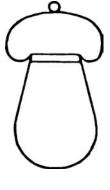
Our model (*Scutellæ*):
Glass, colourless.
Made up of two parts.
Height: 14.5 cm.
(Inventory No. K 1.40)

Vessels

made of two similar glass components

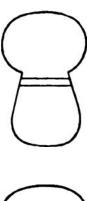
On the plate of instruments of the Latin version of ar-Rāzī's *Sirr al-asrār* in the Riccardiana manuscript, two apparatuses are shown each of which is made up of two similar vessels. The first (no. 2) bears the legend *Cauchil* and is said to have been used for «the sublimation of spirits», the second (no. 13) is called *Scutellæ* and is meant for «the dissolution of spirits».[1] A third illustration of this type of apparatus can be seen in the manuscript of the book preserved in Bologna (University, No. 184).[2] Al-Kindi describes the use of such a vessel in the 73rd recipe of his *K. Kīmiyā᾽ al-ʿiṭr wa-t-taṣʿīdāt*.[3]

Our model (*Cauchil*):
Glass, colourless.
In two parts.
Height: 10 cm.
(Inventory No. K 1.29)

[1] J. Ruska, *Übersetzung und Bearbeitungen*, op. cit., p. 83.
[2] G. Carbonelli, *Sulle fonti storiche della Chimica*, op. cit., p. 110.
[3] K. Garbers, *K. Kīmiyā᾽ al-ʿiṭr wa-t-taṣʿīdāt*, Leipzig 1948 (repr. Natural Sciences in Islam, vol. 72, Frankfurt 2002), pp. 89-90.

Our model (*Alembic* No. 6):
Glass, colourless.
Made up of two parts.
Height: 19 cm.
(Inventory No. K 1.33)

Our model (*Caecum*):
Glass, colourless.
Made up of two parts.
Height: 13 cm.
(Inventory No. K 1.51)

Our model (*Alembic caecum*):
Glass, colourless.
Made up of two parts.
Height: 19 cm.
(Inventory No. K 1.53)

‹blind›

Alembics

(*inbīq aʿmā*)

On the plate of instruments in the Latin version of ar-Rāzī's book, an apparently beakless *alembic* is depicted as no. 6.[1] It displays certain deviations when compared to the instruments shown as nos. 14, 24, and 28. These are known under the name *Alembic caecum*, derived from the Arabic, and belong to the apparatuses for the sublimation of spirits. This instrument is called *qarʿa* and *anbīq* (*inbīq*) in Arabic.[2] The product (sublimate) is collected in the groove of the «blind» cap.

figs. from:
Übersetzung und Bearbeitungen von al-Rāzī's Buch Geheimnis der Geheimnisse by Julius Ruska, p. 235 (83).

[1] J. Ruska, *Übersetzung und Bearbeitungen*, op. cit., p. 83.
[2] Abū Bakr ar-Rāzī, *Kitāb al-Asrār wa-Sirr al-asrār*, op. cit., p. 9.

Distillation cap,
Iran, 3rd-4th/9th-10th cent.
Khalili Collection
No. GLS 199.

Retort, Islamic,
4th-6th/10th-12th cent.,
Science Museum,
London,
after A. Y. al-Hassan,
D. R. Hill,
Islamic Technology,
op. cit. p. 136.

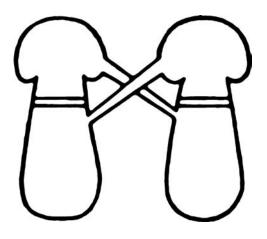
Alembic with beak

Our model (*Alanbic*):
Glass, colourless.
Made up of two parts, a retort
and a cap with a beak.
Height: 25 cm.

Abū Bakr ar-Rāzī[1] mentions the *qarʿ* («gourd», i.e. retort) *wa-l-inbīq ḏāt al-ḫatm* (and cap with a beak) as an apparatus made up of two parts for the distillation of water. A translation of his description on the construction of the retort that should be used for thisw distillation is given above (p. 116).[2] This type of alembic is simply called Alanbic in the Latin version (or adaptation) of ar-Rāzī's book, whereas the name of another alembic, which ar-Rāzī[3] calls *inbīq aʿmā* («blind»), is rendered literally into Latin[4] as *Caecum alembic* or *Alembic caecum*, or simply as *Caecum*.

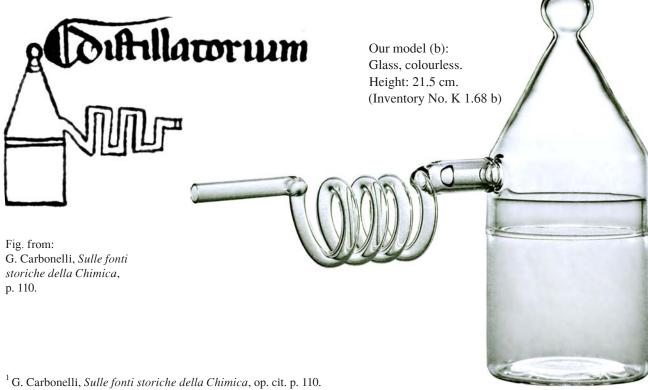
Fig. from:
Übersetzung und Bearbeitungen von al-Rāzī's Buch Geheimnis der Geheimnisse
by Julius Ruska, p. 235 (83).

[1] *Kitāb al-Asrār wa-Sirr al-Asrār*, op. cit., p. 9.
[2] J. Ruska, *Al-Rāzī's Buch*, op. cit., p. 94.
[3] *Kitāb al-Asrār wa-Sirr al-asrār*, op. cit., p. 9.
[4] J. Ruska, *Übersetzung und Bearbeitungen*, op. cit., p. 83.

Our model:
Glass, colourless.
Made up of two parts,
each with a cap
and a retort.
Height: 24 cm.
(Inventory No. K 1.56)

Double Alembic

The instruments depicted in the Latin version of ar-Rāzī's book in the Riccardiana manuscript[1] also include a pair of «double alembics» (*Alembic duplicati*, no. 31) among the devices that are made up of identical vessels. This combination seems to have been widespread in Europe.[2] Our model was reconstructed after the illustration in the Riccardiana manuscript.

Alembic duplicati, fig. from:
Übersetzung und Bearbeitungen von al-Rāzī's Buch…
by Julius Ruska, op. cit., p. 235 (83).

[1] J. Ruska, *Übersetzung und Bearbeitungen*, op. cit., p. 83.
[2] v. e.g. Hieronymus Brunschwig, *Das buch der waren kunst zu distillieren*, Leipzig 1972 (repr. of the edition 1512), fol. 16a, 37a.

Two more forms of

Alembic with beak

In the Bologna manuscript (University, No. 184) of the Latin version of ar-Rāzī's book[1] two more forms of the alembic are preserved that differ from one another in the width and in the shape of the beak. In the second type the beak appears to have been extended as a coil for cooling.

Fig. from:
G. Carbonelli,
Sulle fonti storiche della Chimica, p. 110.

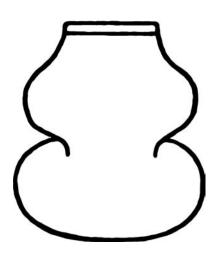
Our model (a):
Glass, colourless.
Height: 21.5 cm.
(Inventory No. K 1.68)

Our model (b):
Glass, colourless.
Height: 21.5 cm.
(Inventory No. K 1.68 b)

Fig. from:
G. Carbonelli, *Sulle fonti storiche della Chimica*,
p. 110.

[1] G. Carbonelli, *Sulle fonti storiche della Chimica*, op. cit. p. 110.

Fig. from: *Übersetzung und Bearbeitungen von al-Rāzī's Buch...* by Julius Ruska, p. 235 (83).

Our model:
Glass, colourless.
Height: 20 cm.
(Inventory No. K 1.52)

The ‹doubled gourd›

A glass vessel in the shape of a «double gourd» (*Cucurbita duplicata*; Arabic probably *qarʿa muṯannā*) is also depicted on the plate of instruments in the Latin version of ar-Rāzī's book[1] in the Riccardiana manuscript (No. 27). We find a similar picture in Hieronymus Brunschwig's book.[2]

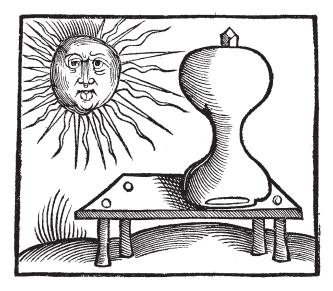
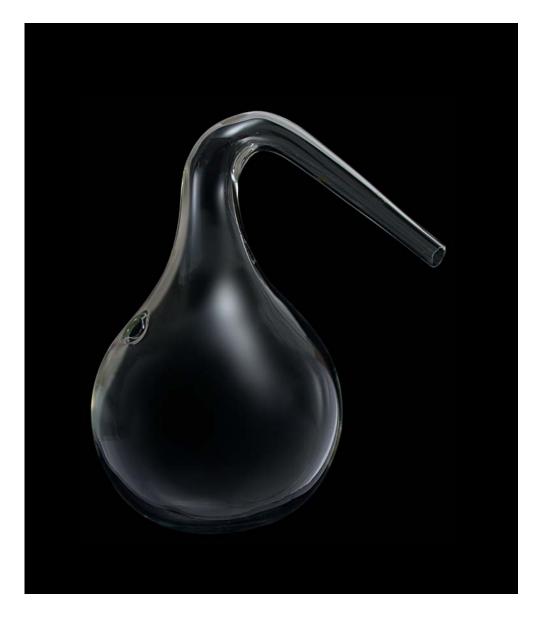



Fig. from Brunschwig, *Das buch der waren kunst zu distillieren*, reprint., fol. 14 b.

[1] J. Ruska, *Übersetzung und Bearbeitungen*, op. cit., p. 83.
[2] *Das buch der waren kunst zu distillieren*, op. cit., fol. 14 b.

Our model:
Glass, colourless.
Height: 14.5 cm.
(Inventory No. K 1.57)

Retort
with a strongly bent beak

The plate of instruments in the Riccardiana manuscript of the Latin version of ar-Rāzī's book depicts another vessel (no. 32) which has a bent beak and bears the caption Canna retroversa. It is classified among vasae congelationis, the apparatuses for solidification. J. Ruska identifies it as the vessel which «is called pelican in more recent works».[1]

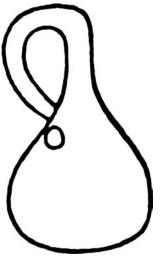



Fig. from:
Übersetzung und Bearbeitungen von al-Rāzī's Buch Geheimnis der Geheimnisse
by Julius Ruska,
p. 235 (83).

[1] J. Ruska, *Übersetzung und Bearbeitungen*, op. cit., pp. 82, 83.

Our model
(*Ampulla*):
Glass, colourless.
Height: 14.5 cm.
(Inventory No.
K 1.35)

Our model
(*Canna*):
Glass, colourless.
Height: 13 cm.
(Inventory No.
K 1.37)

Phials/Round-bottomed Retorts

With a curved neck or a neck bent at right angles

The plate of instruments in the Latin version of ar-Rāzī's *Sirr al-asrār* in the Riccardiana manuscript depicts two vessels for condensation under the numbers 8 (*Ampulla*) and 10 (*Canna*). One of the vessels is equipped with a curved neck, the other with a neck bent at right angles.[1]

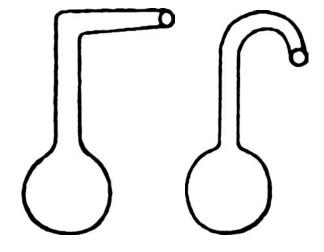
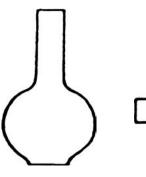
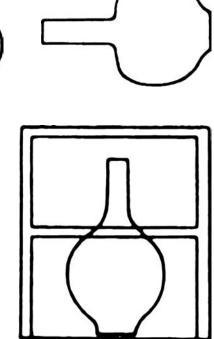
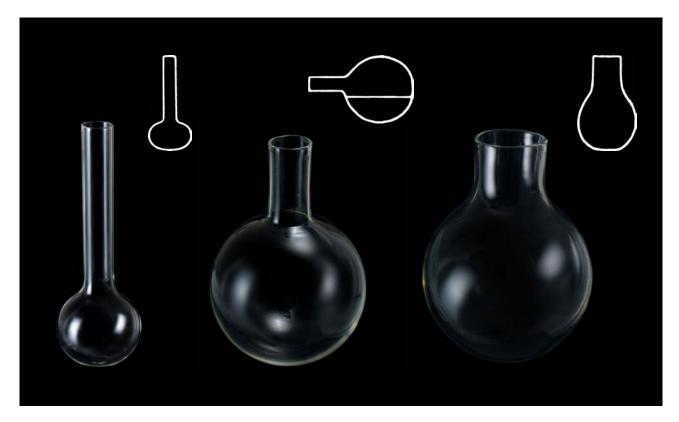



Fig. from: *Übersetzung und Bearbeitungen von al-Rāzī's Buch Geheimnis der Geheimnisse* by Julius Ruska, p. 235 (83).

[1] J. Ruska, *Übersetzung und Bearbeitungen*, op. cit., 83.

Our model (no. 7):
Glass, colourless.
Height: 14 cm.
(Inventory no. K 1.34)

Our model (no. 15):
Glass, colourless.
Height: 13.5 cm.
(Inventory no. K 1.42)

Our model (no. 29):
Glass, colourless.
Height: 23 cm.
(Inventory No. K 1.54)

Phials/flat-bottom Retorts

The plate of instruments of the Latin version of ar-Rāzī's book[1] contains three pictures of retorts for different operations (nos. 7, 15, 29) in the following shapes:

Glass retort, Iran, 4th/10th cent., Museum für Angewandte Kunst, Frankfurt, V 204/5076.

Three figures of *Ampullae* from: *Übersetzung und Bearbeitungen von al-Rāzī's Buch Geheimnis der Geheimnisse* by Julius Ruska, op. cit., p. 235 (83).

[1] J. Ruska, *Übersetzung und Bearbeitungen*, op. cit., p. 83.

Our model
(Ampulla, no.16):
Glass, colourless.
Height: 11.5 cm.
(Inventory No. K 1.55)

Our model
(Ampulla no. 30):
Glass, colourless.
Height: 12.5 cm.
(Inventory No. K 1.58)

Our model
(*Vas diss. sub fimo*, no. 33):
Glass, colourless.
Height: 11 cm.
(Inventory No. K 1.47)

Three figs. of Ampullae (above) from: *Übersetzung und Bearbeitungen von al-Razi's Buch ...* by Julius Ruska, op. cit. p. 235 (83).

Phials/ Retorts
with a round base

Long-necked or short-necked phials or retorts (Arabic qinnīna or qārʿra) with round bases are depicted on the plate of instruments in the Latin version of ar-Rāzī's book[1] in the Riccardiana manuscript. There they bear the numbers 16, 30 and 33.

A similar vessel is also depicted in the Bologna manuscript of the Latin translation of ar-Rāzī's *Sirr al-asrār*.[2]

Fig. from G. Carbonelli, *Sulle fonti storiche della Chimica e dell' Alchimia in Italia*, Rome 1925, p. 110.

Glass retort, Iran, 3rd-5th/9th-11th cent., Museum für Islamische Kunst, Berlin, I 2312.

[1] J. Ruska, Übersetzung und Bearbeitungen, op. cit., p. 83.
[2] G. Carbonelli, op. cit., p. 110, cf. p. 70.

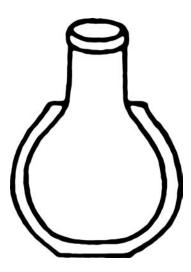
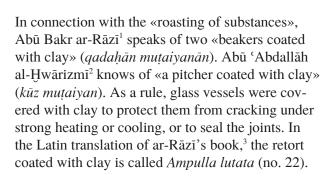



Fig. of an *Ampulla lutata* from:
Übersetzung und Bearbeitungen von al-Rāzī's Buch …
by Julius Ruska, op. cit., p. 235 (83).

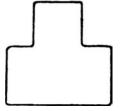
Round Retort
sheathed in clay

Our model:
Glass, colourless.
Coating of unfired clay.
Height: 16 cm.
(Inventory No. K 1.49)

In connection with the «roasting of substances», Abū Bakr ar-Rāzī[1] speaks of two «beakers coated with clay» (*qadaḥān muṭaiyanān*). Abū ʿAbdallāh al-Ḫwārizmī[2] knows of «a pitcher coated with clay» (*kūz muṭaiyan*). As a rule, glass vessels were covered with clay to protect them from cracking under strong heating or cooling, or to seal the joints. In the Latin translation of ar-Rāzī's book,[3] the retort coated with clay is called *Ampulla lutata* (no. 22).

This is the retort reconstructed by us. The 'artificial clay' (*ṭīn al-ḥikma*) which has the necessary properties (resistance against moisture and heat) and is very expensive to produce was described by al-Kindī,[4] ar-Rāzī,[5] al-Hwārizmī[6] and in the Latin Riccardiana manuscript.[7] Known as lutum (English *lute*), it remained an indispensable laboratory cement until recent times.

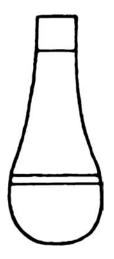
[1] *Kitāb al-Asrār wa-Sirr al-asrār*, op. cit., p. 12; Ruska, *Al-Rāzī's Buch Geheimnis der Geheimnisse*, op. cit., pp. 61, 98.
[2] *Mafātīḥ al-ʿulūm*, op. cit., p. 258; E. Wiedemann, *Zur Chemie bei den Arabern*, op. cit., p. 78 (repr., op. cit., p. 695).
3 J. Ruska, *Übersetzung und Bearbeitungen*, op. cit., p. 83.

[4] K. Garbers, *K. Kīmiyāʾ al-ʿiṭr wa-t-taṣʿīdāt*, Leipzig 1948 (repr. Natural Sciences in Islam, vol. 72, Frankfurt 2002), p. 94.
[5] J. Ruska, *Al-Rāzī's Buch Geheimnis der Geheimnisse*, op. cit., p. 96, § 14.
[6] E. Wiedemann, *Über chemische Apparate bei den Arabern*, op. cit., p. 244 (repr., op. cit., p. 70).
[7] J. Ruska, *Übersetzung und Bearbeitungen*, op. cit., p. 81.

Our model (… esgen):
Glass, colourless.
Height: 10 cm.
(Inventory No. K 1.30)

Our model (Cannina):
Glass, colourless.
Height: 15 cm.
(Inventory No. K 1.31)

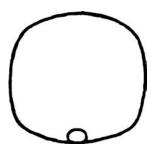
Two vessels
with wide necks (carafes)

On the plate of instruments in the Latin version of ar-Rāzī's *Kitāb Sirr al-asrār*[1] two wide-necked vessels for sublimation are depicted under the names …*esgen* and *Cannina* (nos. 3 and 4). While *cannina* reproduces the Arabic term *qinnīna*, the identification of the first name is beyond my knowledge.

Two figs. from: *Übersetzung und Bearbeitungen von al-Rāzī's Buch Geheimnis der Geheimnisse* by Julius Ruska, op. cit., p. 235 (83).

Glass vessel,
Egypt, Early Islamic,
Athens, Benaki Museum
No. 360 (43/48).

[1] J. Ruska, *Übersetzung und Bearbeitungen*, op. cit., p. 83.

Mace-shaped
Glass vessel

The plate of instruments in the Latin version of ar-Rāzī's *Sirr al-asrār* (Riccardiana manuscript), includes instruments that serve the purpose of «fixing the spirits,» and depicts a glass vessel, obviously in several parts, with the designation Tuba (no. 9).[1]

Tuba, fig. from: *Übersetzung und Bearbeitungen von al-Rāzī's Buch Geheimnis der Geheimnisse*, by Julius Ruska, p. 235 (83).

Our model:
Glass, colourless.
Made up of three parts.
Height: 13 cm.
(Inventory No. K 1.36)

Sphere-shaped
Vessel

The plate of instruments in the Latin version of ar-Rāzī's Sirr al-asrār (Riccardiana manuscript) includes instruments that serve the purpose of the «calcination of spirits», and depicts a spherical vessel without a neck («Phiala») (no. 17).[2].

Phiala, fig from: *Übersetzung und Bearbeitungen von al-Rāzī's Buch Geheimnis der Geheimnisse*, by Julius Ruska, p. 235 (83).

Our model:
Glass, colourless. Diameter: 10 cm.
(Inventory No. K 1.44)

[1] J. Ruska, *Übersetzung und Bearbeitungen*, op. cit., p. 83.
[2] Ibid., p. 83.

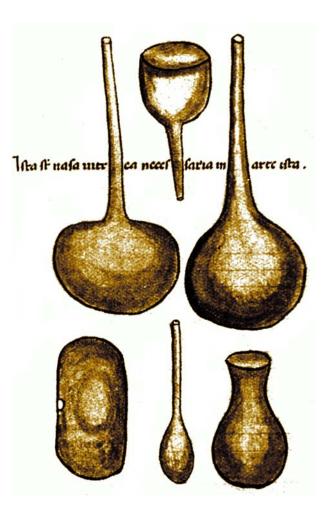
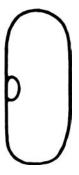



Fig. from: G. Carbonelli, *Sulle fonti storiche della Chimica e dell'Alchimia in Italia*, Rome 1925, p. 138, fig. 161 (bottom left.).

Our model:
Glass, colourless.
Length: 10.5 cm.
(Inventory No. K 1.38)

Another

Vessel

‹for the dissolution of spirits›

Under the caption *Cannutum* (probably from Arabic *qinnīna*) another device for the «dissolution of spirits» (*fusio spiritum*; *ḥall al-arwāh*) appears on the plate of instruments[1] in the Latin version of ar-Rāzī's book in the Riccardiana manuscript. A similar figure is also to be found in the anonymous Latin copy, the illustrations of which were published by G. Carbonelli.[2]

Cannutum, fig from: *Übersetzung und Bearbeitungen von al-Rāzī's Buch ...* by Julius Ruska, p. 235 (83).

[1] J. Ruska, *Übersetzung und Bearbeitungen*, op. cit., p. 83.
[2] Carbonelli, op. cit., p. 138, no. 161.

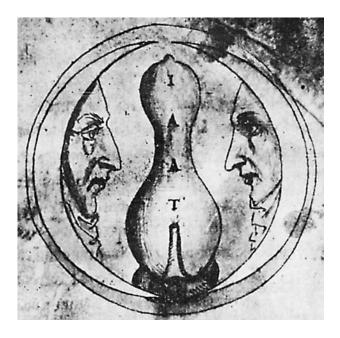
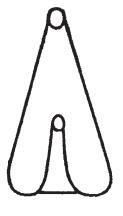



Fig from: G. Carbonelli, *Sulle fonti storiche della Chimica e dell'Alchimia in Italia*, Rome 1925, p. 57.

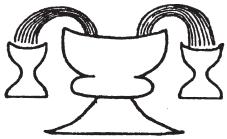
Our model:
Glass, colourless.
Height: 14.5 cm.
(Inventory No. K 1.39)

An Apparatus for the ‹dissolution of spirits›

The plate of instruments in the Latin version of ar-Rāzī's book in the Riccardiana manuscript[1] depicts among the *vasae fusionis spiritum* (*qawārīr li-ḥall al-arwāḥ*) an apparatus that bears the caption Caxa (no. 12). It recalls an illustration included in his book by G. Carbonelli.[2]

Caxa, Fig. from: *Übersetzung und Bearbeitungen von al-Rāzī's Buch* by Julius Ruska, p. 235 (83).

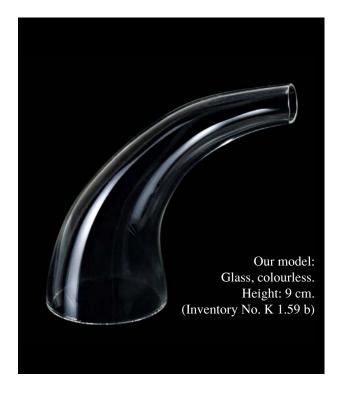
[1] J. Ruska, *Übersetzung und Bearbeitungen*, op. cit., p. 83.
[2] Carbonelli, op. cit., p. 57.

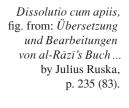
Our model:
Glass, colourless and wick.
Height: 13 or 5.3 cm.
(Inventory No. K 1.69)

Capillary filter
Beaker

In the chapter on the washing of chemical substances, Abū Bakr ar-Rāzī speaks, inter alia, of the procedure of washing by means of a *rāwūq fī ǧām* (a filter in a «goblet»),[1] but unfortunately does not describe the device in the chapter on apparatuses. As J. Ruska noted, in the «Book of Secrets,» at one time «the instruction is given to soak up the moisture by means of a wick that passes through a hole in the lid of the Uṯāl and to let the moisture drip into a sugar bowl. In half a dozen passages the instruction is found to wash or to clean something with or on the *rāwūq*».[2] We learn about the shape of the apparatus from the illustrations in the Latin version of the text, both in the Riccardiana manuscript in Florence (No. 26) and from the manuscript in the University Library in Bologna.[3]

Destillatio per filtrum, fig. from: *Übersetzung und Bearbeitungen von al-Rāzī's Buch ...* by Julius Ruska, op. cit., p. 235 (83).

Fig. from: G. Carbonelli, *Sulle fonti storiche ...*, op. cit., p. 110.

[1] *Kitāb al-Asrār wa-Sirr al-asrār*, op. cit., p. 25.
[2] *Al-Rāzī's Buch Geheimnis der Geheimnisse*, op. cit., pp. 62-63.
[3] G. Carbonelli, op. cit., p. 110.

Cornu

The plate of instruments of the Riccardiana manuscript of the Latin version of ar-Rāzī's book depicts, among the devices for the dissolution of chemical substances, a horn-like object with the caption Cornu (no. 37). Perhaps it has to do here with a funnel.[1]

Cornu, fig. from: *Übersetzung und Bearbeitungen von al-Rāzī's Buch ...* by Julius Ruska, op. cit., p. 235 (83).

Our model:
Glass, colourless.
Height: 9 cm.
(Inventory No. K 1.59 b)

A spherical Device for dissolution

Dissolutio cum apiis, fig. from: *Übersetzung und Bearbeitungen von al-Rāzī's Buch ...* by Julius Ruska, p. 235 (83).

The plate of instruments in the Riccardiana manuscript of the Latin version of ar-Rāzī's book depicts, among the apparatuses for the dissolution of substances, a spherical vessel with an attachment of a right-angled pipe at the top and a small retort inside (no. 42). The meaning of the caption *Dissolutio cum apiis* is not quite clear.[2]

Our model:
Glass, yellowish-brown, made up of two parts.
Retort with a short neck of clear glass, 10 cm high.
(Inventory No. K 1.60)

[1] J. Ruska, *Übersetzung und Bearbeitungen*, op. cit., p. 82, 83.
[2] Ibid., p. 83.

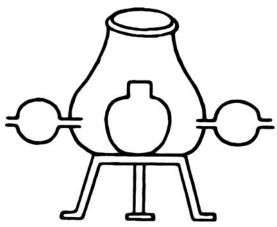



Fig. from: *Übersetzung und Bearbeitungen von al-Rāzī's Buch …* by Julius Ruska, op.cit., p. 235 (83).

Our model:
Clay, fired.
Tripod of steel.
Total height: 38 cm.
(Inventory No. K 1.62)

The Kiln ‹that fans itself›

Among the «instruments for the treatment of non-metals,» Abū Bakr ar-Rāzī[1] mentions a kiln that «fans itself» (*nāfiḫ nafsahū*): «The self-ventilating device is a kiln (*tannūr*) whose lower part is narrower than the upper part. It stands on three feet and is placed upon a stand whose walls are perforated. In the middle of its base there is a hole through which the ashes fall out. Into its lowest part coals are shuffied and that which is to be calcinated is placed on it and is buried in the coal and covered with coal. It should be placed in a windy location. Its fire is extremely strong, it calcinates the metals and amalgamates them and melts them.»[2] The text from al-Ḫwārizmī's *Mafātīḥ al-ʿulūm* amplifies ar-Rāzī's text in an important respect, in the sense that there the substance to be treated is put on the fire in a pitcher coated with clay.[3] This corresponds with the figure with the caption *Nafis* (no. 42), which has become accessible through the Latin version of ar-Rāzī's book.[4]

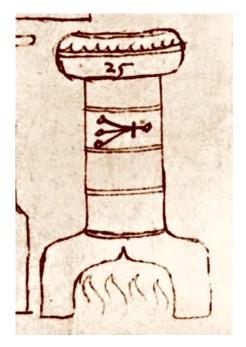
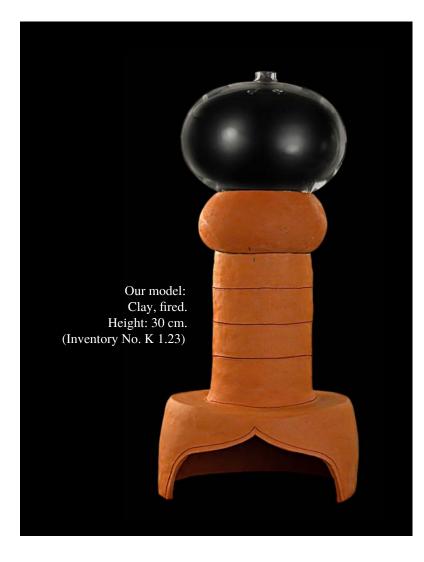
[1] *Kitāb al-Asrār wa-Sirr al-asrār*, op. cit., p. 12; v. also Abū ʿAbdallāh al-Ḫwārizmī, *Mafātīḥ al-ʿulūm*, pp. 257-258.

[2] J. Ruska, *Al-Rāzī's Buch Geheimnis der Geheimnisse*, p. 99.

[3] v. E. Wiedemann, *Zur Chemie bei den Arabern*, op. cit., p. 78 (repr., p. 695).

[4] J. Ruska, *Übersetzung und Bearbeitungen*, op. cit., p. 83.

Fig. from W. Ganzenmüller, op. cit., p. 297, no. 25

Our model:
Clay, fired.
Height: 30 cm.
(Inventory No. K 1.23)

Vas
decoctionis mercuris

Among the kilns characterised by «Moorish style», as depicted in the Munich manuscript of the *Liber florum Geberti* (Cod. Lat. 25110), the following specimen appears for heating mercury with a process that is prescribed in Gebert's «fourth flower».[1] In the illustration it is very clear to see the manner in which the kiln was constructed with ring-shaped components.

Plate from *De operationibus alchymiae*, 14th/15th cent. MS Munich, Bayer. Staatsbibl. CLM 405, fol. 171 b.

[1] W. Ganzenmüller, *Liber florum Geberti. Alchemistische Öfen und Geräte in einer Handschrift des 15. Jahrhunderts*, in: Quellen und Studien zur Geschichte der Naturwissenschaften und der Medizin (Berlin), 8/1942/273-303, esp. pp. 288, 299 and 297, fig. 4, no. 25.

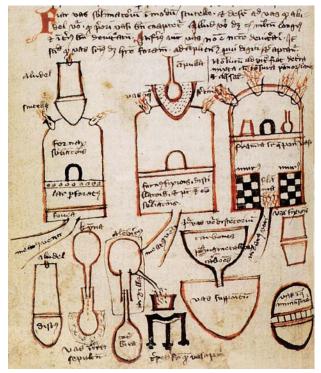
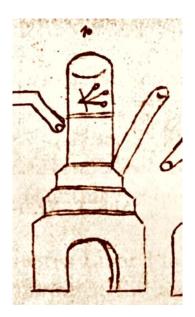



Fig. from the Paris Geber manuscript (Bibl. Nat. MS lat. 6514), after A.Y. al-Hassan, D. R. Hill, *Islamic Technology*, op. cit., p. 136.

Aludel

For the process of sublimation, i.e. the transition of a solid substance to the gaseous stage, illustrations are provided in the treatise *ʿAin aṣ-ṣanʿa wa-ʿaun aṣ-ṣanaʿa* by Abu l-Ḥakīm Muḥammad b. ʿAbdalmalik al-Ḫwārizmī al-Kāṯī (writing in 426/1034) of Baghdad[1] and in the *Summa collectionis complementi occulte secretorum nature* of Geber (Latinised edition of the Arabic works by Ǧābir b. Ḥaiyān) in the Paris manuscript[2] (Bibl. Nat. MS lat. 6514). With the help of these illustrations, we were able to reconstruct our model of the relevant with just a little bit of imagination on our part.

Our model:
Clay, fired.
Aludel of glass.
Height: 51 cm.
(Inventory No. K 1.70)

The upper part, made of glass, is called *uṯāl* in the Arabic text and the kiln itself *mustauqad*. In Latin the terms are *alutel* and *furnus*. From the Latin text we also learn that the hole at the upper tip (*foramen*) is meant for the escape of the gases formed during the sublimation.

[1] F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 4, Leiden 1971, pp. 291-292; H. E. Stapleton, R. F. Azo, *Alchemical equipment in the eleventh century, A. D.*, in: Memoirs of the Asiatic Society of Bengal 1/1905/47-71.

[2] M. Berthelot, *La chimie du moyen âge*, op. cit., vol. 1, p. 149 ff.; A. Y. al-Hassan, D. R. Hill, *Islamic Technology*, op. cit., p. 136.

Our model:
Clay, fired.
Height: 48 cm.
(Inventory No. K 1.07)

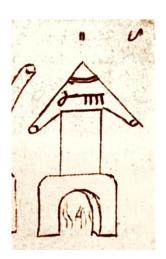



Fig. from:
W. Ganzenmüller, op. cit., p. 296, no. 10.

Kiln

for chemical operations

Our model was built after an illustration in the *Liber florum Geberti* (no. 10).[1]

Kiln

with a cap and two beaks

Reconstructed after an illustration in the *Liber florum Geberti* Geberti (no. 11).[2]

Our model:
Clay, fired.
Height: 30 cm.
(Inventory No. K 1.08)

Fig. from:
W. Ganzenmüller, op. cit., p. 296, no. 11.

[1] v. W. Ganzenmüller, op. cit., p. 296, 297, no. 10.
[2] Ibid., p. 296, 299, no. 11.

Fig. from:
W. Ganzenmüller, op. cit.,
p. 302, no. 74.

Kiln

reconstructed after an illustration in the *Liber florum Geberti* (no. 74).[1]

Our model:
Clay, fired.
Height: 19.50 cm.
(without retorts).
(Inventory No.
K 1.09)

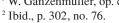
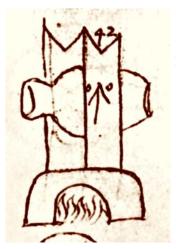



Fig. from:
W. Ganzenmüller,
op. cit., p. 302, no. 76.

Another kiln

A kiln for heating solid substances, modelled after an illustration in *Liber florum Geberti* (no. 76).[2]

Our model:
Clay, fired.
Made of two parts.
Height: 29.50 cm.
(Inventory No. K 1.10)

[1] W. Ganzenmüller, op. cit., p. 296, no. 74.
[2] Ibid., p. 302, no. 76.

Kiln
for heating a retort suspended above it

Reconstructed after an illustration in the *Liber florum Geberti* (no. 42).[1]

Our model:
Clay, fired.
Height: 21.5 cm.
Retort (height = 11.5 cm) of clear glass, hung in a wire-frame
(Inventory No. K 1.12)

Fig. from:
W. Ganzenmüller, op. cit., p. 299, no. 42.

Kiln
with alembic

In this model two apparatuses depicted in the *Liber florum Geberti*,[2] a kiln (no. 44) and an alembic (no. 37), were combined with one another.

Our model:
Kiln of clay, fired.
Height: 21 cm.
(Inventory No. K 1.13)
Alembic: Glass, colourless.
Made of two parts.
Height: 48 cm.
(Inventory No. K 1.14)

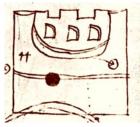
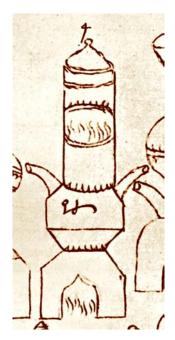



Fig from:
W. Ganzenmüller, op. cit., p. 299, no. 37 (sic!) and 44.

[1] W. Ganzenmüller, op. cit., p. 299, no. 42.
[2] Ibid., p. 296, 299, no. 37, 44.

Kiln
with a glass lead attachment

A kiln for heating chemical substances, reconstructed after an illustration in the *Liber florum Geberti* (no. 4).[1]

Our model:
Clay, fired.
Height: 51 cm
with a glass lid attachment.
(Inventory No. K 1.15)

Fig. from:
W. Ganzenmüller,
op. cit., p. 295, no. 4.

Vas
decoctionis elixir

Construction for boiling the elixir, after an illustration in the *Liber florum Geberti* (no. 40).[2]

Our model:
Clay, fired.
Height: 52 cm.
(Inventory No. K 1.16)

Fig. from:
W. Ganzenmüller, op. cit., p. 299, no. 40.

[1] W. Ganzenmüller, op. cit., p. 295, no. 4.
[2] Ibid., p. 299, no. 40, cf. p. 300.

Cauldron
with lion paws

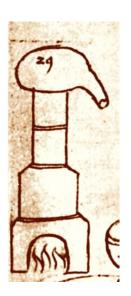
Reconstructed after an illustration in the *Liber florum Geberti* (no. 48).[1]

Our model:
Clay, fired.
Made of two parts.
Height: 25 cm.
(Inventory No. K 1.17)

Fig. from:
W. Ganzenmüller,
op. cit., p. 299, no. 48.

Kiln
with a retort in the form of a cap

Reconstructed after an illustration in *Liber florum Geberti* (no. 29).[2]

Our model:
Clay, fired.
Height: 27.5 cm.
Alembic of clear glass.
Total height: 34.5 cm.
(Inventory No. K 1.20)

Fig. from:
W. Ganzenmüller, op. cit., p. 298, no. 29.

[1] W. Ganzenmüller, op. cit., p. 296, 299, no. 48.
[2] Ibid., p. 298, 296, no. 29.

Kiln

in the form of an elephant's trunk

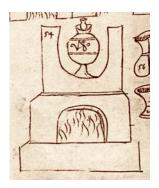
Reconstructed after an illustration in the *Liber florum Geberti* (no. 17).[1]

Our model:
Clay, fired.
Height: 36 cm.
(Inventory No. K 1.19)

Fig. from:
W. Ganzenmüller,
op. cit., p. 297, no. 17.

Kiln

Due to the symbol, declared by Ganzenmüller as *furnellus lune et veneris*, a small silver and copper kiln. Reconstructed after the illustration in the *Liber florum Geberti* (no. 54).[2]

Our model:
Clay, fired.
Height: 38 cm,
including the retort.
(Inventory No. K 1.71)

Fig. from:
W. Ganzenmüller,
op. cit., p. 300, no. 54.

[1] W. Ganzenmüller, op. cit., p. 297, no. 17, cf. p. 302.
[2] Ibid., p. 300, no. 54, cf. p. 296.

Fig. from:
W. Ganzenmüller, op. cit., p. 295, no. 2.

Apparatus
of unknown function

Reconstructed after a sketch in the *Liber florum Geberti* (no. 2).[1] The two openings of the glass could have served for producing a stream of air.

Our model: Clay, fired.
Height: 23 cm, including the glass.
(Inventory No. K 1.11)

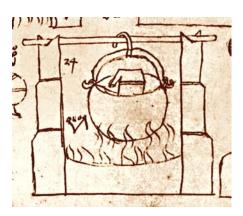



Fig. from:
W. Ganzenmüller, op. cit., p. 297, no. 24.

Hearth
with ‹a kettle full of vinegar›

Reconstructed after an illustration in the *Liber florum Geberti* (no. 24).[2]

Our model:
Hearth: clay, fired, Height: 38 cm.
Kettle: copper, engraved, diameter 22 cm.
Alembic inside the kettle.
(Inventory No. K 1.22)

[1] W. Ganzenmüller, op. cit., p. 295, no. 2, cf. p. 296.
[2] Ibid., p. 297, no. 24, cf. p. 298.

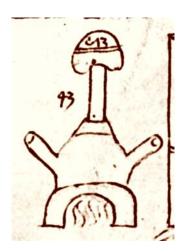



Fig. from:
W. Ganzenmüller,
op. cit., p. 299, no. 43.

Kiln
with Alembic

Reconstructed after an illustration in the *Liber florum Geberti* (no. 43).[1]

Our model:
Clay, fired.
Height: 64 cm,
including the alembic.
(Inventory No. K 1.25)

Our model:
Clay, fired.
Height: 31 cm.
(Inventory No. K 1.21)

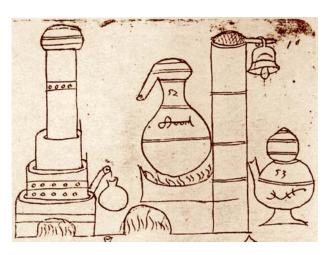
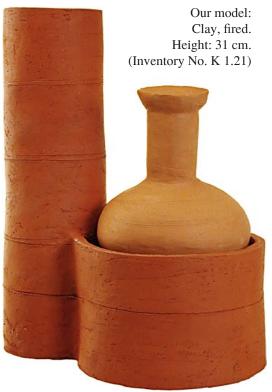



Fig. from: W. Ganzenmüller,
op. cit., p. 300, no. 52.

Kiln

Reconstructed after an illustration in the *Liber florum Geberti* (no. 52).[2]

[1] W. Ganzenmüller, op. cit., p. 299, no. 43.
[2] Ibid., p. 300, no. 52, cf. pp. 296, 297, 298-299.

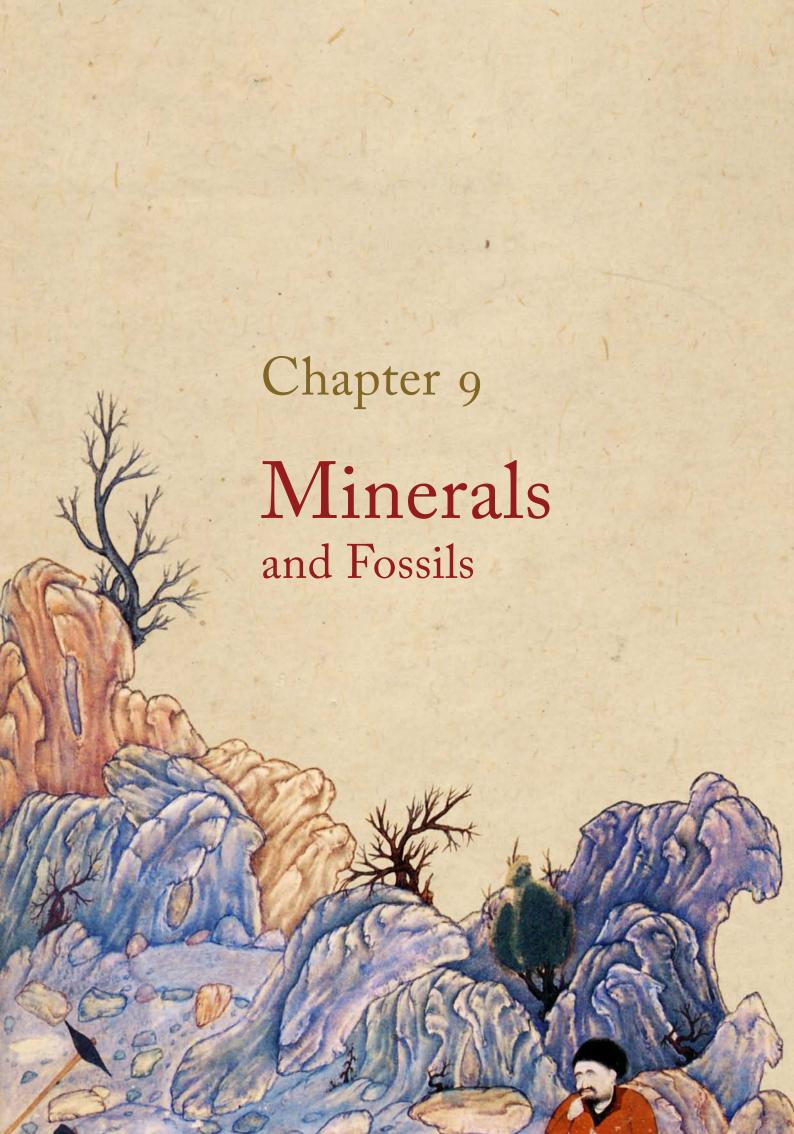
A Kiln

for the production of artificial gems

Our model:
Clay, fired, cold painted.
Height: 53 cm.
(Inventory No. K 1.06)

Fig from MS Gotha 1347, after Hassan/Hill, *Islamic Technology*, op. cit., p. 167.

The partly preserved manuscript of the *Ǧawāhir al-funūn wa-ṣ-ṣanāʾiʿ fī ġarīb al-ʿulūm wa-l-badāʾiʿ* (Gotha 1347, fol. 55a, 57a) depicts, inter alia, two «carefully executed ink drawings of kiln constructions.» The author, Muḥammad b. Muḥammad Aflāṭūn al-Harmasī al-ʿAbbāsī al-Bisṭāmī, is unknown so far.[1] The extant manuscript contains excerpts from 6 of the original 28 chapters of a large book on mineralogy.[2] E. Wiedemann[3] was the first to draw attention to the two kilns through his short descriptions and he was the first to publish the drawings.

[1] v. C. Brockelmann, *Geschichte der arabischen Litteratur*, suppl., volume 2, p. 1033.
[2] v. Alfred Siggel, *Katalog der arabischen alchemistischen Handschriften Deutschlands*, Part 2, Berlin 1950, pp. 83–86, cf. Wilhelm Pertsch, *Die arabischen Handschriften der Herzoglichen Bibliothek zu Gotha*, vol. 3, Gotha 1881 (repr. Frankfurt 1987), pp. 17–18.
[3] *Zur Geschichte der Alchemie. IV. Über chemische Apparate bei den Arabern*, in: Zeitschrift für angewandte Chemie (Leipzig and Berlin) 34/1921/528-530, esp. pp. 528-529 (repr. in: Wiedemann, *Gesammelte Schriften*, vol. 2, esp. pp. 957-960); idem, *Beiträge zur Mineralogie etc. bei den Arabern*, in: Studien zur Geschichte der Chemie, Festgabe für O. v. Lippmann, Berlin 1927, pp. 48-54, esp. pp. 51-54 (repr. in: *Gesammelte Schriften*, vol. 2, esp. pp. 1207-1210); see also A. Y. al-Hassan, D. R. Hill, *Islamic Technology*, op. cit., p. 167.

Kiln
of Zosimus

Our model:
Clay, fired and glazed.
Height: 43 cm.
(Inventory No. K 1.05)

Fig from MS
Gotha 1347
after Hassan/Hill,
op. cit. p. 154.

This kiln ascribed to Zosimus[1] (4th or 5th cent. A.D.) appears in the Gotha manuscript mentioned above (p. 152) in a carefully executed drawing but without any explanation whatsoever. This drawing was also published by E. Wiedemann. There is no doubt that Zosimos worked with a kiln. But the apparatus connected with his name seems to be the result of a development in the construction of chemical apparatuses that took place only after the 5th/11th century in the Arab-Islamic culture area.

[1] v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 4, Leiden 1971, pp. 73-77.

Chapter 9

Minerals
and Fossils

Introduction

In one of the few studies on the history of mineralogy where the role of the Arabic-Islamic cultural sphere in this field is discussed, Julius Ruska[1] stated in 1912: "History of science has to deal with Arabic literature in three ways. History of science encounters the Muslims first as pupils of the Greeks, endeavouring, with the help of the Syrians and Persians, who knew the subject and the language, to transfer the treasures of Greek wisdom within reach into their own language and to utilise them. Studying the Greeks aroused the urge towards independent research and discovery, and as a fruit of this scientific enthusiasm we encounter an enormous corpus of treatises on matters dealing with mathematics and astronomy, natural sciences and medicine. After a few generations we find the Arabs as the teachers of the scientifically impoverished Latin West and we find their works translated, commented upon, published and recognised as authoritative works down to the 16th century and further." J. Ruska penned these lines almost one hundred years after the appearance of the first orientalist studies on this subject. These were an Italian translation[2] of the book on mineralogy, the *Azhār al-afkār fī ǧawāhir al-aḥǧār* by Aḥmad b. Yūsuf at-Tīfāšī (d. 651/1253) and, at about the same time, a German translation[3] of excerpts from the Persian *Ǧawāhirnāma* by Muḥammad b. Manṣūr ad-Daštakī (early 8th/14th cent.). In the course of time, both before and after J. Ruska, a few Arabic books on mineralogy were edited and translated into European languages. Moreover, a large number of studies and bibliographical works appeared without which the compilation of our selection[4] of minerals would have been inconceivable. In spite of all the commendable attempts so far, the following questions seem to have been rarely asked: Which new minerals were discussed by the Arabic-Islamic scholars as compared to their Greek masters? Which new sites were discovered in Islamic times? What were their own experiences, observations, classifications and theories of their origin? Likewise there are hardly any studies on the impact of Arabic mineralogy on the advances made in the Occident. We can safely follow J. Ruska in his chronological overview of the participating cultures which played a decisive role in the history of science.[5] And his observations are not restricted to the field of mineralogy alone: "In this connection, we have to distinguish basically between four large culture areas: the Egyptian-Babylonian, the Graeco-Roman, the Islamic, and the Christian-Occidental, which leads into the modern era. Basically, there is a significant connection between these cultures; the Far East also follows them." Unfortunately the Greeks, with all their astonishingly vast knowledge of mineralogy, provide us with hardly any clues as to which of the minerals mentioned by them and which part of information about those minerals are their own in origin and what knowledge they borrowed from other cultures. In this connection the Arabic-Islamic successors differ greatly from their teachers. Not only do they cite their Greek sources with amazing precision and [**158**] mention with regard to each individual mineral what information they had adopted; frequently they give, beside the author's name, also the title of the work, sometimes even the relevant chapter.

[1] *Das Steinbuch des Aristoteles mit literargeschichtlichen Untersuchungen nach der arabischen Handschrift der Bibliothèque nationale herausgegeben und übersetzt*, Heidelberg 1912, pp. 1 (reprint in: Natural Sciences in Islam, vol. 27, Frankfurt 2001, pp. 1-216, esp. pp. 9).

[2] *Fior di pensieri sulle pietre preziose di Ahmed Teifascite*, ed. and transl. Antonio Raineri, Florence 1818 (reprint in: Natural Sciences in Islam, vol. 31, Frankfurt 2001, pp. 1-178).

[3] Josef von Hammer, *Auszüge aus dem persischen Werke Ǧawāhirnāma* [orig. Arabic] *i.e. das Buch der Edelsteine, von Mohammed Ben Manssur*, in: Fundgruben des Orients, vol. 6, Vienna 1818, pp. 126-142 (v. *Das Steinbuch des Aristoteles*, pp. 31); Āġābuzurg aṭ-Ṭahrānī, *aḏ-Ḏarīʿa ilā taṣānīf aš-šīʿa*, vol. 5, Teheran 1363/1944, pp. 283.

[4] Our selection stems from the large collection of minerals of the Institut für Mineralogische Rohstoffe of the Technical University, Clausthal. For this we wish to express our thanks here. We also thank Dr. Armin Schopen for his manifold support in this connection.

[5] *Die Mineralogie in der arabischen Literatur*, in: Isis (Brussels) 1/1913-14/341-350, esp. pp. 342 (reprint in: Natural Sciences in Islam, vol. 28, Frankfurt 2001, pp. 255-264, esp. pp. 256).

Their main sources included the Arabic translation of Dioscorides's (2nd half of the 1st cent. B.C.) *Περὶ ὕλης ἰατρικῆς* and Galen's (2nd half of the 2nd cent. A.D.) *Περὶ κράσεως καὶ δυνάμεως τῶν ἁπλῶν φαρμάκων*. Apart from several authentic and not authentic Greek pharmaceutical and mineralogical treatises, a pseudo-Aristotelian book of stones also reached the Arabic-Islamic culture area. It was translated into Arabic by a certain Lūqā b. Isrāfiyūn, as he himself states. This work in which 72 stones are described holds the foremost position among the sources of Arabic mineralogy. According to J. Ruska,[6] it is likely that "a Syrian who was familiar with the Greek and also with the Persian sources and traditions authored the book in the period of translations, before the middle of the 9th century." According to the author of these lines, however, this work had its origin in Late Antiquity (ca. 5th-6th cent. A.D.) and was translated into Arabic in the 2nd/8th or the 3rd/9th century.[7] This and other pseudo-texts and Hermetic treatises circulated in the Mediterranean region during Pre-Islamic and Early Islamic times. The importance of their contents was realised quite early, they were translated, treated as authentic works and cited under their pseudonyms.
We must also mention that, together with the authentic and pseudo Greek texts on mineralogy, pharmaceutics, and medicine, not only sober matter-of-fact descriptions of minerals reached the Arabic-Islamic world, but also, for instance, beliefs related to the magical effects of stones and their use as amulets. When we find such elements even in the works of Dioscorides and Galen, we must not fall into the error of thinking that the cultural importance of these works or their importance for the history of science becomes diluted because of this. Arabic-Islamic mineralogy also contains some traces of Indian[8] and Middle-Persian[9] sources, but these are of minimal consequence because of the dominant position of the Greek sources.
In view of the modest status of the contemporary research on Arabic mineralogy, we make here the bold attempt to communicate some of the discoveries and interpretations of Arabic mineralogy which are of interest for the history of mineralogy and geology. J. Ruska[10] gave some broad outlines of the knowledge he gained from his intensive study of the material in the first half of last century. Thus he finds in Arabic cosmological and nature-philosophical treatises a "stronger emphasis on the general issues of the origin of minerals and their chemical properties," and also of issues concerning geology—as compared to their pharmacological treatises. In this connection, what he finds particularly interesting are the observations of the fifth treatise of the Encyclopedia of the Brethren of Purity (Iḫwān aṣ-Ṣafāʾ, 4th/10th cent.) on the origin of minerals, which "contains much on geology that has not been noticed so far. Thus, e.g. the minerals are divided into three classes according to the time required for their formation. The first group is formed in dust, loam and salt steppes and needs just one year for maturing; here the rapid formation of steppe salt, gypsum and such salts in the dry climate of the Near East can be recognised. The second group is of the stones that form slowly at the bottom of the sea, such as corals and pearls. The last group consists of metals and gems which originate in the interior of stones, in mountain caves; some of these only reach maturity after centuries. The fixed stars in the sky make one full revolution in 36,000 [**159**] years,[11] the conditions on earth change correspondingly, cultivable land becomes desert, deserts become cultivable, steppes and mountain ranges emerge from the oceans, deserts and mountain ranges sink into the sea. The mountain ranges heat up under the rays of the sun, they dry up, burst and crumble, become gravel and sand; heavy showers of rain turn them into sludge in the beds of mountain rivulets, rivers and streams; these lead them to the oceans, the lakes and the marshes;

[6] *Das Steinbuch des Aristoteles*, op. cit., pp. 44-45 (reprint pp. 44-45).
[7] v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 4, pp. 103.
[8] v. Muḥammad Yaḥyā al-Hāšimī, *al-Maṣādir al-hindīya li-kutub al-aḥǧār al-ʿarabīya*, in: Ṯaqāfat al-Hind (New Delhi) 12,3/1961/100-115 (reprint in: Natural Sciences in Islam, vol. 30, Frankfurt 2001, pp. 227-242).
[9] Jean Pierre de Menasce, *Un lapidaire pehlevi*, in: Anthropos 37-40/1942-45/180-185; M. Yaḥyā al-Hāšimī, *al-Maṣādir al-fārisīya li-Kitāb al-Ǧamāhir fī maʿrifat al-ǧawāhir li-l-Bīrūnī*, in: ad-Dirāsāt al-adabīya (Beirut) 1959, issues 2-3, pp. 58-65 (reprint in: Natural Sciences in Islam, vol. 30, pp. 219-226).
[10] *Die Mineralogie in der arabischen Literatur*, op. cit., pp. 345-346 (reprint op. cit., pp. 259-260).
[11] The Iḫwān aṣ-Ṣafāʾ obviously did not know the much improved value for the precession (v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 6, pp. 26).

the oceans act on them through the surf and the pounding of the waves, and spread them in layers at their bottom; they are deposited one above the other; they adhere to one another, form mountains and hills under water; like the sand in the steppes and deserts, they rise gradually and become firm land on which plants take over, while, to compensate for it at other places, the ocean overflows its coasts and spreads across firm country. Here it is possible to see the main features of Joh. Walther's[12] theory of deserts and Ch. Lyell's[13] principle of geology, and it would be an interesting task to examine how far these geological views rest on independent observations and ideas and how far they must be traced back to those of the Greek geographers, for example."

"The enumeration of stones and the extensive subdivision of salt-like substances" which occur in the "Book of Secrets" (*Kitāb al-Asrār*) by Abū Bakr ar-Rāzī (d. 313/925) were regarded by J. Ruska as "an innovation introduced by Rāzī".[14] Ruska also made the observation that some books are very precise in their information about the places of the occurrence of minerals.[15] This is confirmed by other sources which were not accessible to him or were not known in his times.

"Greater attention is paid to the physical properties which can be ascertained directly or with the simplest tools. Whether the mineral is heavy or light, hard or soft, smooth or rough, brittle, whether it can be split or hammered, whether it is soluble or not, whether it is lustrous or dull, transparent or opaque, and what colours it has—all this is listed, though not systematically, but in many cases with good powers of observation, likewise the behaviour of the mineral in fire or against acids, its taste and odour." [16]

On the question of the advances made by the Arab authors as against their Greek sources in the descriptions of the minerals, Ruska again provides an example. On the book of stones by Aḥmad at-Tīfāšī (d. 651/1253) he remarks as follows: "The description of each stone is given in five chapters, the first of which deals with the cause of the formation of the stone in its mine, the second deals with the localities where it occurs, the third with its good and bad properties, the fourth with its specific powers and effects, the fifth with its commercial value." "In describing the medicinal and chemical properties, at-Tīfāšī depends greatly on the work by [pseudo-]Aristotle, yet he offers much new information on the places of occurrence, on the method of differentiating between different varieties, on the defects and flaws, on the price and the use of gems."[17]

J. Ruska cites likewise an instructive example of the description of the places of occurrence according to at-Tīfāšī: "On the quarrying of emeralds in Upper Egypt highly interesting information is provided by our author. According to Bauer's *Edelsteinkunde*,[18] the old Egyptian emerald mines were rediscovered only under Meḥemmed ʿAlī by the Frenchman Fr. Cailliaud in 1816, but the operations were stopped again after a short time, and no information was available about the operation of the mines from the period after the Roman occupation.[**160**] But this is not correct in so far as the mines are mentioned by al-Iṣṭaḫrī in the 4th/10th century as well as by al-Idrīsī about 545/1150. Al-Masʿūdī already reports at length about the mining of emeralds and their varieties in the *Murūǧ aḏ-ḏahab* (ed. Barbier de Meynard, vol. 3, pp. 43 ff.). The information given by at-Tīfāšī can be summarised as follows: Emeralds are found on the border between Egypt and Ethiopia in a mountain range that stretches to the sea near Aswan. The senior inspector of mines, who was appointed by the sultan, informs that the first thing to be encountered in the emerald mines is black talc which, when exposed to fire, appears like golden marcasite. Through further digging the soft red sand in which emeralds occur is reached. Only small stones which are used for rings are found in the sand; the large ones and the complete emeralds are to be found in galleries and veins."[19]

[12] On him, v. Ilse Seibold, *Der Weg zur Biogeologie. Johannes Walther (1860-1937)*, Berlin etc. 1992.
[13] Born 1797 in Kinnordy (Scotland), died 1875 in London.
[14] *Al-Rāzī's Buch Geheimnis der Geheimnisse mit Einleitung und Erläuterungen in deutscher Übersetzung* by Julius Ruska, Berlin 1937 (Quellen und Studien zur Geschichte der Naturwissenschaften und der Medizin, vol. 6), pp. 37.
[15] *Die Mineralogie in der arabischen Literatur*, op. cit. pp. 343 (reprint op. cit. pp. 257).
[16] ibid, pp. 343 (reprint pp. 257).
[17] ibid, pp. 348 (reprint pp. 262).
[18] Max Bauer, *Edelsteinkunde. Eine allgemein verständliche Darstellung der Eigenschaften, des Vorkommens und der Verwendung der Edelsteine, nebst einer Anleitung zur Bestimmung derselben, für Mineralogen, Edelsteinliebhaber, Steinschleifer, Juweliere*, Leipzig 1909, pp. 390.
[19] *Die Mineralogie in der arabischen Literatur*, op. cit., pp. 349

It was without doubt a great advance when the Arab-Islamic mineralogists discovered a procedure to evaluate minerals[20] and ores according to their specific weight.[21] The pycnometer invented by al-Bīrūnī (1st half of the 5th/11th cent.) made it possible for him and his successors to determine the specific weight with amazing accuracy (see below, V.9).

It may also be mentioned that al-Bīrūnī[22] refuted the popular notion that all salt water everywhere on earth was transformed into fresh water at a specific hour on the 6th day of January every year and that he contradicted a method which had come down from Aristotle for the desalination of sea water. This has to do with the attempt to extract fresh water out of sea water with the help of a waxen vessel, as described in Aristotle's meteorology: "Actually, if a waxen vessel with the neck closed tightly is submerged into the sea, after 24 hours it would contain some amount of water which had seeped into it through the waxen walls and this water would be drinkable because the earthy and salty parts had been 'filtered out'."[23] Abū ʿAlī Ibn Sīnā (d. 428/1037) also deals with the origin of rocks in the section on meteorology of his *Kitāb aš-Šifāʾ*. Until the 19th century this section, available in Latin under the title *Liber de mineralibus Aristotelis*, was thought to be the work of the Greek philosopher Aristotle (see below, pp. 163). On the topic that interests us, M. Y. Haschmi of Aleppo has published several studies. From his work *Die geologischen und mineralogischen Kenntnisse bei Ibn Sīnā*[24] we cite the following passages on the origin of minerals:[25] "Stones are formed in two ways, either through drying up as with the formation of loam, or through ossification. Loam dries up and turns gradually into stone. If it is not [**161**] fatty, it will decompose before it becomes stone. Ibn Sīnā recounts that in his youth he saw on the banks of the River Ǧaiḥūn [Amu-Darya] a type of loam which turned into stone within 23 years. Stones originate in running water in two ways, firstly through evaporation and secondly through gradual precipitation. Ibn Sīnā also observed that some waters condense to stones and pebbles with different colours when they drip upon a certain spot. Some waters ossify, but only when they come into contact with certain types of stone. From this he concluded that there were some types of earth which had mineralogical properties to bring about the ossification of water. The beginning of stone formation occurs either through loam-like substances or through other substances that contain much water. In the latter case, the rock is formed either through a mineral force that causes the solidification or through the predominance of the earthy parts as in the case of salt formation … Water turns into loam and loam also turns into water. Thus the stones are either dried in the sun as in loam formation or through the hardening of water and through drying up."[26]

After this Ibn Sīnā discusses the reason for the fossilisation of plants and animals. In conjunction with this, he also mentions his own observations made in Central Asia. One of these is connected with the so-called "lightning tube": "Sometimes stone-like or iron bodies form through lightning. In the land of the Turks (Turkistān), after thunder and lightning, copper-like bodies [in the form of lances, *aǧsām*

(reprint op. cit., pp. 263).

[20] Al-Bīrūnī reports in his *Kitāb al-Ǧamāhir fī maʿrifat al-ǧawāhir* (ed. F. Krenkow, Hyderabad 1355/1936, pp. 50) on the existence of a book on the prices of precious stones, written in Damascus during the reign of Marwān b. ʿAbdalmalik (65/685-86/705) which he had come across. E. Wiedemann (*Über den Wert von Edelsteinen bei den Muslimen*, pp. 353, reprint in: Natural Sciences in Islam, vol. 28, pp. 237) earns the credit for having been the first to draw attention to this early source. The manuscript of the book by al-Bīrūnī, which Wiedemann used, seems to have contained a more detailed description of the old book (to be more precise, the booklet) than the printed edition which is at our disposal.

[21] E. Wiedemann, *Über den Wert von Edelsteinen bei den Muslimen*, in: Der Islam (Strasburg) 2/1911/345-358 (reprint in: Natural Sciences in Islam, vol. 28, Frankfurt 2001, pp. 229-242).

[22] *al-Āṯār al-bāqiya ʿan al-qurūn al-ḫāliya*, ed. by Eduard Sachau, Leipzig 1878 (repr. Islamic Mathematics and Astronomy, vol. 30, Frankfurt 1998), pp. 250; Engl. transl. idem, *The Chronology of Ancient Nations*, London 1879 (repr. Islamic Mathematics and Astronomy, vol. 31, Frankfurt 1998), pp. 240; v. also E. Wiedemann, *Entsalzung des Meerwassers bei Bîrûnî*, in: Chemiker-Zeitung (Heidelberg) 46/1922/230 (reprint in: *Gesammelte Schriften* vol. 2, Frankfurt 1984, pp. 1019).

[23] Edmund O. von Lippmann, *Die "Entsalzung des Meerwassers" bei Aristoteles*, in: Chemiker-Zeitung (Heidelberg) 1911, pp. 629 ff., 1189 ff., and in: Abhandlungen und Vorträge zur Geschichte der Naturwissenschaften von E. O. von Lippmann, vol. 2, Leipzig 1913, pp. 157-167, esp. pp. 167.

[24] In: Zeitschrift der Deutschen Morgenländischen Gesellschaft (Wiesbaden) 116/1966/44-59.

[25] *Kitāb aš-Šifāʾ. Ṭabīʿīyāt*, part 5: *al-Maʿādin wa-l-āṯār al-ʿulwīya*, ed. by Ibrāhīm Madkūr, ʿAbdalḥalīm Muntaṣir, Saʿīd Zāyid, ʿAbdallāh Ismāʿīl, Cairo 1965, pp. 3 ff.; M. Y. Haschmi, op. cit., pp. 44 ff.

[26] Ibn Sīnā, Šifāʾ op. cit., pp. 3-4; Haschmi, op. cit., pp. 44-45.

nuḥāsīya ʿalā haiʿat as-sihām] were formed. Ibn Sīnā tried to melt a piece, but it burned with green smoke and left an ash-like substance behind. He also heard about iron that had fallen from the air."[27] No doubt, the "copper-like body in the form of a lance" was a lightning tube or a fulgurite; these are sand grains fused together in the form of a tube which form in sand through flashes of lightning. A first description of this phenomenon was given by Karl Gustav Friedler in 1817.[28]

According to Eric J. Holmyard, in his discussion of the formation of mountain ranges and stones, Ibn Sīnā had anticipated quite early the conclusions of Leonardo da Vinci (1452-1519) and Nicolas Steno (1631-1686).[29]

In the history of mineralogy, reference is made particularly to Ibn Sīnā's classification of minerals. He divides them into four classes: 1. stones (*aḥǧār*), 2. ores (*ḏāʿibāt*, i.e. substances that can be melted), 3. substances that can be burnt (*kabārīt*, sulphura = varieties of sulphur), 4. salts (*amlāḥ*, substances that are soluble in water). However, I do not believe that this is in fact the "only thing" which "really survived the Middle Ages" as Karl Mieleitner[30] opined in 1922. At the end of this introduction, when we now raise the question of the continuation of Arabic-Islamic mineralogy in the Occident, we must be aware of the fact that we are not dealing with one of the fundamental areas of Arabic science, such as mathematics, astronomy, medicine and geography which exceptionally many scholars dealt with and left numerous works. Therefore the process of the reception and assimilation in the Occident of this peripheral subject looks different to that of the core subjects. Thus, there is hardly any influence worth mentioning, e.g., on the encyclopaedist Alexander Neckam (1157-1227), one of the most eminent figures in the phase of reception. [**162**] In his book entitled *De naturis rerum liber* he does mention plenty of stones, but he does not give any descriptions.[31]

In my view, this explains why there are no more than isolated references to mineralogy in the works of Roger Bacon, the great European nature philosopher of the 13th century.[32]

It is the book on minerals by Albertus Magnus (1193-1280), said to be the "best mineralogical work of the Occidental Middle Ages," which shows for the first time noticeable traces of texts translated from the Arabic. These Arabic texts include Ibn Sīnā's book of stones, the pseudo-Aristotelean book of stones and a few other materials that were made available in Latin translation from the Arabic originals by the convert, Constantinus Africanus (d. 1085 in Salerno). It is striking that in his *Libri V de mineralibus* he adopts Ibn Sīnā's classification of stones, which we mentioned above, placing, however, the salts and the substances that can be burnt (sulphura) between stones and metals.[33] In a manner that is instructive for our question, K. Mieleitner [34] explains the nature of the special knowledge and the capacities of a personality as important for the assimilation process as Albertus Magnus is: "All in all, the mineralogical knowledge of Albertus is very meager, and in this field he excels his contemporaries only slightly. He relies mainly on the statements of his sources, but at least in his case there are the beginnings, though only in modest form, of making observations of his own. He was not familiar with the best writings of the Mohammedans, their works on the specific weight were completely unknown to him—as also to all other mineralogists of the Occidental Middle Ages—since he had at his disposal only imperfect Lain extracts of Arabic texts. Of course, Albertus also laboured under the opinions of his times, particularly the alchemical beliefs. His chemical knowledge was very meagre, although according to his own words he had read and stud-

[27] Šifāʾ, op. cit., pp. 5; Haschmi, op. cit., pp. 45; idem, *Geologische Beobachtungen bei Avicenna*, in: Der Aufschluß. Zeitschrift für die Freunde der Mineralogie und Geologie (Heidelberg, Göttingen) 7/1956/15-16.

[28] v. Rudolph Zaunik, *Kurze Notiz*, in: Mitteilungen zur Geschichte der Medizin und der Naturwissenschaften 41/1961/163. In F. M. Feldhaus, *Die Technik. Ein Lexikon der Vorzeit, der geschichtlichen Zeit und der Naturvölker*, Wiesbaden 1914 (repr. Munich 1970), column 110 one can read: "The clergyman Leonhard David Hermann found at Massel in Silesia one such [a lightning tube] first in 1706, but he explained it as 'a fruit of a subterranean fire' (…). The tube is preserved in the Mineralogisches Kabinett in Dresden. Around 1796 one farmer Hentzen found such a tube in the Senne near Paderborn and correctly called it a 'lightning tube'."

[29] *Makers of Chemistry*, Oxford 1931, pp. 72.

[30] *Zur Geschichte der Mineralogie. Geschichte der Mineralogie im Altertum und im Mittelalter*, in: Fortschritte der Mineralogie, Kristallographie und Petrographie (Jena) 7/1922/427-480, esp. pp. 480, cf. ibid, pp. 461.

[31] v. K. Mieleitner, *Zur Geschichte der Mineralogie*, op. cit., pp. 466.

[32] ibid, pp. 477.

[33] ibid, pp. 466, 468.

[34] ibid, pp. 473, 474.

ied much and had undertaken journeys to find out about the nature of metals. In the explanation of the physical and chemical properties, he finds in fact very few difficulties; as a rule he has at once a completely adequate explanation for everything, in the manner of scholastic philosophy. He modified Avicenna's excellent division of the minerals into four classes, which was not very fortunate, but at the same time very necessary because he knew so few salts and combustible bodies among the minerals that he could not put them as an equally important class next to stones and minerals. His book on precious stones differs from the numerous others of the Middle Ages only in the sense that he at least includes a few of his own observations, even if those are for the most part incorrect." The first Arabic book with mineralogical content that reached the Occident in Latin translation was apparently *al-Iʿtimād fī l-adwiya al-mufrada* by Aḥmad b. Ibrāhīm Ibn al-Ǧazzār (d. 369/979).[35] It is a book of drugs in four parts, the fourth of which is devoted to minerals and mineral medicaments.[36] It saw the light of the day in Salerno under the title *Liber de gradibus* as a work of the above-mentioned north-African convert Constantinus Africanus, who translated several books from the Arabic, reworked them arbitrarily, and attributed them to himself or to a Greek authority.[37]

This adaptation circulated for seven hundred years as the work of Constantinus Africanus, parallel to the Latin translation of a certain Stephanus de Caesaraugusta (Zaragoza, written 1233) which bears the name of the actual author and the title *Liber fiduciae de simplicibus medicinis*.

[**163**] The mineralogical knowledge of the Arabic-Islamic culture area also reached the Occident through Latin and Hebrew translations of the chemical-alchemical books by Ǧābir b. Ḥaiyān and Abū Bakr ar-Rāzī. In his study *Übersetzung und Bearbeitungen von al-Rāzīs Buch Geheimnis der Geheimnisse*[38], which appeared in 1935, Julius Ruska could show what kind of elaborations and adaptations were done to this book that contains an important chapter on minerals.

Wide popularity in the Occident was also enjoyed by the above-mentioned pseudo-Aristotelean book of stones which was obviously translated into Latin from the Arabic in the 6th/12th century. Of course, it was considered for centuries a book by Aristotle, not only in the Occident, but also in the Islamic world. For the author of these lines it is, however, a Greek pseudo-epigraph from Late Antiquity that was first translated into Arabic and from there into Latin.

In conclusion, we may mention another work which too was translated at first from the Arabic and was circulated as the work by Aristotle. It is the Liber de mineralibus Aristoteles, which was known for centuries, besides the *Tria vero ultima Avicennae capitula transtulit Aurelius de arabico in latinum*, until E. J. Holmyard and D. C. Mandeville[39] demonstrated that both the texts are a part of the section on natural sciences (*ṭabīʿīyāt*) in Ibn Sīnā's Kitāb aš-Šifāʾ.

[35] v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 3, pp. 304-307.

[36] Facsimile ed., Frankfurt 1985.

[37] v. Moritz Steinschneider, *Constantinus Africanus und seine arabischen Quellen*, in: Archiv für pathologische Anatomie und Physiologie und für klinische Medicin (Berlin) 37/1866/351-410, esp. pp. 361-363 (reprint in: Islamic Medicine, vol. 43, pp. 1-60, esp. pp. 11-13; idem, *Constantin's lib. de gradibus und Ibn al-Ǧezzar's Adminiculum*, in: Deutsches Archiv für Geschichte der Medicin und medicinischen Geographie (Leipzig) 2/1879/1-19 (reprint in: Islamic Medicine vol. 94, pp. 320-338).

[38] In: Quellen und Studien zur Geschichte der Naturwissenschaften und der Medizin, vol. 6, Berlin 1935, pp. 153-239.

[39] *Avicennae De congelatione et conglutinatione lapidum being sections of the Kitâb al-Shifâʾ*. The Latin and Arabic texts edited with an English translation of the latter and with critical notes by E. J. Holmyard and D. C. Mandeville, Paris 1927 (reprint in: Natural Sciences in Islam, vol. 60, Frankfurt 2001, pp. 147-240).

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ʿAlī b. Rabban aṭ-Ṭabarī, *Firdaus al-ḥikma* = *Firdaus al-ḥikma fi ṭ-ṭibb* li-Abi l-Ḥasan ʿAlī b. Sahl Rabban aṭ-Ṭabarī, ed. Muḥammad Zubair aṣ-Ṣiddīqī, Berlin 1928.

Bauer, *Edelsteinkunde* = Max Bauer, *Edelsteinkunde. Eine allgemein verständliche Darstellung der Eigenschaften, des Vorkommens und der Verwendung der Edelsteine, nebst einer Anleitung zur Bestimmung derselben, für Mineralogen, Edelsteinliebhaber, Steinschleifer, Juweliere*, Leipzig 1909.

J. Berendes = *Des Pedanios Dioskurides aus Anazarbos Arzneimittellehre in fünf Büchern. Übersetzt und mit Erklärungen versehen von* Julius Berendes, Stuttgart 1902 (repr. Wiesbaden 1970).

Bīrūnī, *Ǧamāhir* = *Kitāb al-Ǧamāhir fī maʿrifat al-ǧa-wāhir* min taṣnīf al-ustāḏ Abi r-Raiḥān Muḥammad b. Aḥmad al-Bīrūnī, ed. Fritz Krenkow, Hyderabad, 1355/1936 (repr. Natural Sciences in Islam, vol. 29, Frankfurt 2001).

Clément-Mullet, see Tīfāšī

A. Dietrich, *Dioscurides triumphans* = *Dioscurides triumphans. Ein anonymer arabischer Kommentar (Ende 12. Jahrh. n. Chr.) zur Materia medica. Arabischer Text nebst kommentierter deutscher Übersetzung*, 2 vols., Göttingen 1988.

EI = *Enzyklopaedie des Islām. Geographisches, ethnographisches und biographisches Wörterbuch der muhammedanischen Völker.* Ed. M.Th. Houtsma et al., 4 vols. and supplement, Leiden and Leipzig 1913–1938.

EI New Ed. = *The Encyclopaedia of Islam. New Edition*. Prepared by a number of leading Orientalists, edited by…H.A.R. Gibb et al., Leiden 1960 ff.

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French. transl. Leclerc = *Traité des simples par Ibn el-Bëithar*. Traduction par Lucien Leclerc, 3 vols., Paris, 1877, 1881, 1883 (Notices et extraits des manuscrits de la Bibliothèque nationale, vols. 23, 25, 26) (repr. Islamic Medicine, vols. 71–73, Frankfurt 1996).

German transl. Sontheimer = *Große Zusammenstellung über die Kräfte der bekannten einfachen Heil- und Nahrungsmittel* von…Ebn Baithar. Transl. from the Arabic by Joseph v. Sontheimer, 2 vols., Stuttgart 1840, 1842.

Ibn al-Ǧazzār, *Iʿtimād* = *Kitāb al-Iʿtimād fī'l-adwiya al-mufrada* (Engl. titel: *The Reliable Book on Simple Drugs*) by Ibn al-Jazzār, facsimile ed. F. Sezgin, Frankfurt 1985.

Lat. transl. *Liber fiduciæ* = Lothar Volger, *Der Liber fiduciae de simplicibus medicinis des Ibn al-Jazzār in der Übersetzung von Stephanus de Saragossa*. Übertragung aus der Handschrift München, Cod. Lat. 253, Würzburg 1941 (Texte und Untersuchungen zur Geschichte der Naturwissenschaften. Heft 1) (repr. Islamic Medicine, vol. 39, Frankfurt 1996, pp. 225-334).

Idrīsī, *al-Ǧāmiʿ li-ṣifāt aštāt an-nabāt* = *Kitāb al-Jāmiʿ li-ṣifāt ashtāt al-nabāt wa-ḍurūb anwāʿ al-mufradāt* (titre anglais: *Compendium of the Properties of Diverse Plants and Various Kinds of Simple Drugs*), facsimile ed. F. Sezgin, 3 vols., Frankfurt 1995.

Leclerc, see Ibn al-Baiṭār

Muwaffaqaddīn al-Harawī, *Abniya* = *al-Abniya ʿan ḥaqā'iq al-adwiya* ta'līf Muwaffaqaddīn Abū Manṣūr ʿAlī al-Harawī, ed. Aḥmad Bahmanyār and Ḥusain Maḥbūbī Ardakānī, Teheran 1346/1967 (Intišārāt-i Dānišgāh-i Tihrān. No. 1163).

Transl. Achundow = Abdul-Chalig Achundow, *Die pharmakologischen Grundsätze (Liber fundamentorum pharmacologiae) des Abu Mansur Muwaffak bin Ali Harawi zum ersten Male nach dem Urtext übersetzt und mit Erklärungen versehen*, in: Historische Studien aus dem Pharmakologischen Institut der Kaiserlichen Universität Dorpat (Halle) 3/1893/135–414, 450–481 (repr. Islamic Medicine, vol. 50, Frankfurt 1996, pp. 7–319).

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Schönfeld, see Tamīmī

Sontheimer, see Ibn al-Baiṭār

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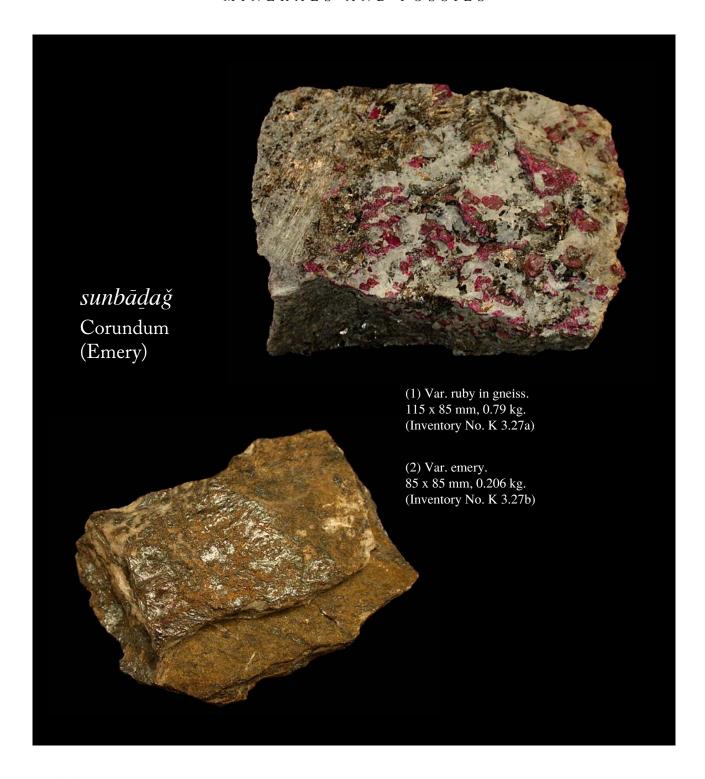
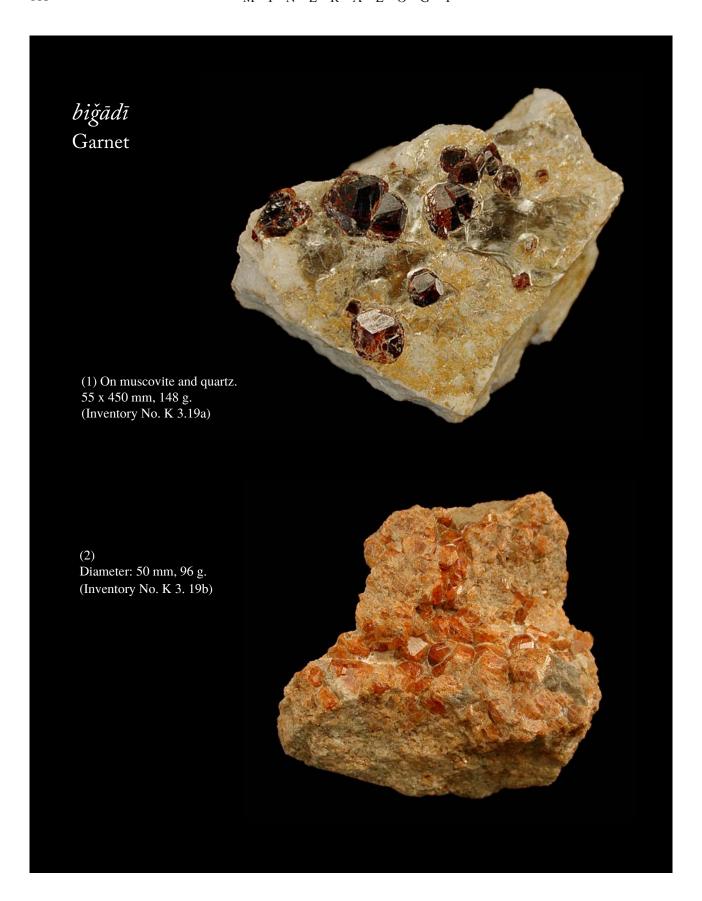

almās

Diamant

11 pieces, white and tinted.
Diameter: ca. 1.5-5 mm. Total weight: ca. 5 ct. (5 carats = 1 g).
(Inventory No. K 3.14)

Diamond is referred to as the hardest of all stones which, unbreakable in itself, can reduce to small pieces all other stones (and metal, with the exception of black lead). Arabic sources mention only India as the deposit site.

Steinbuch des Aristoteles, pp. 105–106, 149–150 (reprint op. cit., pp. 113–114, 157–158); Tamīmī, *Muršid,* pp. 111–113, 191–193; Bīrūnī, *Ǧamāhir,* pp. 92–102; Ibn al-Ǧazzār, *Iʿtimād*, facsimile ed., pp. 157–158; Qazwīnī, *ʿAǧāʾib al-maḫlūqāt,* pp. 236–237; Ibn al-Baiṭār, *Ǧāmiʿ,* vol. 4, pp. 126–127 (French transl. Leclerc, vol. 3, pp. 272; German transl. Sontheimer, vol. 2, pp. 466–467); Tīfāšī, *Azhār al-afkār,* pp. 24–25 (reprint op. cit. pp. 36–37); J. Ruska, *Der Diamant in der Medizin*, in: Zwanzig Abhandlungen zur Geschichte der Medizin. Festschrift Hermann Baas…, Hambourg and Leipzig 1908, pp. 121–130 (reprint in: Natural Sciences in Islam, vol. 27, Frankfurt 2001, pp. 239–248).

sunbāḏaǧ
Corundum
(Emery)

(1) Var. ruby in gneiss.
115 x 85 mm, 0.79 kg.
(Inventory No. K 3.27a)

(2) Var. emery.
85 x 85 mm, 0.206 kg.
(Inventory No. K 3.27b)

Sunbāḏaǧ is a Persian term; in Greek the stone is called σμύϱιδος. It is a hard stone which has the property of being able to grind metal and stone (corundum is still used today in the production of emery paper). Because of its hardness it is considered a "deputy" (*nā'ib*) of diamond (see Bīrūnī, *Ǧamāhir*, p. 102). It is also called *yāqūt aḥmar* (ibid, p. 103).
Sudan, Sri Lanka and Isfahan in Persia are mentioned in Arabic sources as the locations of deposits.

Dioscorides, book 5, chapter 165; v. J. Berendes p. 553; *Steinbuch des Aristoteles*, op. cit., pp. 106, 150-151 (reprint op. cit., pp. 114, 158-159); Ibn al-Baiṭār, *Ǧāmiʿ*, vol. 3, p. 40 (French transl. Leclerc, vol. 2, pp. 299-300; German transl. Sontheimer, vol. 2, pp. 63-64); Qazwīnī, *ʿAǧā'ib al-maḫlūqāt*, p. 228; Tīfāšī, *Azhār al-afkār*, p. 40 (reprint op. cit., p. 21).

biğādī
Garnet

(1) On muscovite and quartz.
55 x 450 mm, 148 g.
(Inventory No. K 3.19a)

(2)
Diameter: 50 mm, 96 g.
(Inventory No. K 3. 19b)

v. *Steinbuch des Aristoteles*, op. cit., pp. 102, 143-144 (reprint op. cit., pp. 110, 151-152); Tīfāšī, *Azhār al-afkār*, pp. 22-23 (reprint op. cit., pp. 38-39).

balḫaš (from Persian *balaḫš*)
Spinel, Ruby Spinel

(1) dark, 10 pieces,
diameter: 3-5 mm.
Total weight: 10 ct.
(Inventory No. K 3.49a)

(2) light, 15 pieces,
diameter: 1.5-3 mm.
Total weight: 8 ct.
(Inventory No. K 3.49b)

Described by at-Tīfāšī (*Azhār al-afkār*, p. 19, reprint p. 42) as related to the ruby (*yāqūt*), this stone is identified with the term *laʿl* (likewise "ruby" etc.) by Ibn al-Akfānī (*Nuḫab aḏ-ḏaḫāʾir*, pp. 755-756): "*Balaḫš* is called *laʿl* in Persian. It is a red transparent stone and it is in fact the red that is called *musfir*, it is also pure. In colour and lustre, it has a striking resemblance to a beautiful *yāqūt*. It differs from it in hardness so that it is cut when the two minerals collide with one another. That is why it must be polished with gold-coloured marcasite, which is the most excellent polishing material for this precious stone. There is one type that resembles the *bahramānī* and is known under the name *al-yāzakī*; it ranks the highest and is the most precious." "At the time of the Buyids (321/933-448/1056), it was sold for the same price as *yāqūt*, until it came to be better known; then its price sank and it was decided that it should be sold by *dirhams* and not by *miṯqāls*, in order to differentiate it from the *yāqūt*. There are specimens tending to white and there are some which tend to the colour of violets (*banafsaǧīya*); these two are less valuable than the first mentioned." "It is found in the East, three days journey from Badaḫšān. This is the gate for it, so to speak, [through which it comes to other countries]. Some spinels occur with transparent coatings and some without. Pieces weighing more than 100 dirham have been noticed. In earlier times the price of each dirham was 20 dinar and sometimes more."[1]
Al-Bīrūnī (*Ǧamāhir* pp. 81-88) lists the stone under the name *al-laʿl al-badaḫšī*, and the same term is used also by al-Ḫāzinī (*Mīzān al-ḥikma*, p. 138, reprint op. cit., p. 295).
In 1818 J. Hammer-Purgstall[2] identified *balḫaš* listed by at-Tīfāšī as spinel. A generation later, E. Quatremère compiled a series of statements on the stone from Arabic and Persian sources in his *Histoire des Sultans Mamlouks de l'Égypte*, écrite en arabe par Taki-Eddin-Ahmed-Makrizi, traduite en français …, vol. 2, Paris 1845, p. 71.[3]

[1] With slight changes adapted from E. Wiedemann, *Zur Mineralogie im Islam*, op. cit., pp. 216-217 (reprint op. cit., pp. 188-189).
[2] cf. *Steinbuch des Aristoteles*, op. cit., p. 32 (reprint op. cit., p. 40).
[3] Quatremère's statements were translated by E. Wiedemann, *Zur Mineralogie im Islam*, op. cit., pp. 235-236 (reprint op. cit., pp. 207-208).

banfaš (from Persian *banafš*)
Zircon (hyacinth)

Diameter: 17 mm, 50 ct.
(Inventory No. K 3.58)

According to at-Tīfāšī (*Azhār al-afkār*, p. 19, repr. p. 42), *banfaš* as well as *balḫaš* (spinel) and *biǧādī* (garnet) belong to the types (*anwāʿ*) and varieties (*ašbāh*) of *yāqūt* (ruby): "The wise man (ḥakīm) says that these three were originally meant to become ruby, but this had been prevented by external influences like too high or too low moisture, lack of warmth or rest. That is why they turned into stones which do not resist fire."

There are said to be four classes (*aṣnāf*) of *banfaš*. The first is called *mādīnī*. It is of a clear light-red colour. The second is called *asādast* and is black. The third (without a name) is yellow. The fourth remains without any description (*Azhār al-afkār*, p. 21, reprint p. 40). J. J. Clément-Mullet[1] identified *banfaš* as zircon.[2]

[1] *Essai sur la minéralogie arabe*, in: Journal Asiatique, sér. 6, 11/1868/5-81, 109-253, 502-522, esp. p. 117 (repr. in Natural Sciences in Islam, vol. 31, Frankfurt 2001, pp. 179-422, esp. p. 265).
[2] On this, v. Oken, *Allgemeine Naturgeschichte*, vol. 1, pp. 150-152; Bauer, *Edelsteinkunde*, pp. 426-432.

ǧamast
Amethyst

(1) Diameter: ca. 95 mm, 0.49 kg.
(Inventory No. K 3.04a)

(2) 180 x 70 mm, 0.77 kg.
(Inventory No. K 3.04b)

About the stone al-ǧamast, also called al-ǧamaz, Ibn al-Akfānī (d. 749/1348) says in his book *Nuḫab aḏ-ḏaḫāʾir fī aḥwāl al-ǧawāhir*:[1] "It is a stone that resembles the violet-coloured *yāqūt* (*al-yāqūt al-banafsaǧī*). The most precious variety sold for the highest price is the rose-coloured variety (*wardī*). It is found near aṣ-Ṣafrāʾ in the Ḥiǧāz. Some specimens are found which are covered with a white coating; they resemble the snow on the surface of which there is some reddishness." The deposit sites are Wašǧird in Persia and the region around the city of aṣ-Ṣafrāʾ in the Ḥiǧāz.
In medicine it was believed that the stone strengthened the brain and the stomach.

Bīrūnī, *Ǧamāhir*, p. 194; Tīfāšī, *Azhār al-afkār*, p. 49 (reprint op. cit., p. 12, v. also Clément-Mullet, op. cit., pp. 211-216, reprint op. cit., pp. 359-364); Ibn al-Baiṭār, *Ǧāmiʿ*, vol. 1, p. 168 (French transl. Leclerc, vol. 1, pp. 366-367; German transl. Sontheimer, vol. 1, p. 258)

[1] Ed. Cheikho, in: al-Mašriq (Beirut) 11/1908/763, translation E. Wiedemann, *Zur Mineralogie im Islam* (*Beiträge zur Geschichte der Naturwissenschaften XXX*), in: Sitzungsberichte der Physikalisch-medizinischen Sozietät (Erlangen) 44/1912/205-256, esp. pp. 226-227 (reprint in: Natural Sciences in Islam, vol. 28, Frankfurt 2001, pp. 177-228, esp. pp. 198-199)..

(1) Transparent
Height: 65 mm, 77 g.
(Inventory No. K 3.08a)

(2) cloudy, xenomorphic.
Height: 150 mm, 0.7 kg.
(Inventory No. K 3.08b)

Seals made of
Rock Crystal
see below,
V, p. 171.

(3) Quartz
60 x 35 mm, 95 g.
(Inventory No. K 3.42a)

(4) Coarse
120 x 80 mm, 0.5 kg.
(Inventory No. K 3.42b)

billaur, ballūr, mahā

Rock Cristal

In the pseudo-Aristotelian book of stones (see above, p. 117) rock crystal is called a stone that resembles glass. This view was also generally held by Arab scholars.

Upper Egypt, Indian Ocean (al-Baḥr al-aḫḍar), Armenia and Sri Lanka are mentioned as the deposit sites.

Rāzī, *Asrār wa-sirr al-asrār,* p. 4; *al-Rāzī's Buch Geheimnis der Geheimnisse,* p. 87; Tamīmī, *Muršid,* pp. 97, 184; Ibn al-Baiṭār, *Ǧāmiʿ,* vol. 4, pp. 167–168 (French transl. Leclerc, vol. 3, pp. 342–343; German transl. Sontheimer, vol. 2, p. 534); Bīrūnī, *Ǧamāhir,* pp. 181–186; Tīfāšī, *Azhār al-afkār,* p. 53 (reprint op. cit., p. 8).

zumurrud
Emerald

Diameter: 12 mm, enclosed in rock: 85 x 50 mm.
Total weight: 120 g.
(Inventory No. K 3.48)

Zumurrud and *zabarǧad* (v. the following) are generally considered in Arabic sources to be one and the same stone. Some mineralogists are of the view that both are found in the same mines and that *zabarǧad* is the less valuable variety.
Upper Egypt, the localities of Sindān and Kambāyāt in India and a region called Buga in the Far East are mentioned as deposit sites.[1]

[1] On the deposit sites, v. E. Wiedemann, *Zur Mineralogie im Islam*, op. cit., pp. 239-242 (reprint op. cit., pp. 211-214).

Steinbuch des Aristoteles, op. cit., pp. 98-99, 134-135 (reprint op. cit., pp. 106-107, 142-143); Tamīmī, Muršid, pp. 43-48, 146-150; Bīrūnī, *Ǧamāhir*, pp. 160-169; Qazwīnī, *ʿAǧāʾib al-maḫlūqāt*, p. 227; Ibn al-Baiṭār, *Ǧāmiʿ*, vol. 2, pp. 166-167 (French transl. Leclerc, vol. 2, pp. 216-217; German transl. Sontheimer, vol. 1, p. 537); Tīfāšī, *Azhār al-afkār*, pp. 13-16 (reprint op. cit., pp. 45-48); Ibn al-Akfānī, *Nuḫab aḏ-ḏaḫāʾir*, op. cit., pp. 760-761.

zabarǧad

Beryl is related in mineralogy to emerald. Arabic mineralogists could not agree whether *zabarǧad* and *zumurrud* were the same kind of stones or different ones. On the sources, see above under emerald.

(2) Greenish
Diameter: 18 mm, 35 ct.
(Inventory No. K 3. 10b)

(1) Greenish-yellow
Diameter: 22 mm, 55 ct.
(Inventory No. K 3.10a)

ʿain al-hirr

Cat's Eye

Diameter: 34 mm, 30 g.
(Inventory No. K 3.24)

Jean-Jacques Clément-Mullet[1] translates the Arabic name into French as *œil-de-chat* and identifies the stone as quartz chatoyant.
At-Tīfāšī (*Azhār al-afkār*, pp. 28-29, reprint pp. 35-36) considers the stone to be an insufficiently developed ruby which is mined together with the ruby as an inferior variety. He complains that none of the books of stones known to him mentioned this stone.

[1] *Essai sur la minéralogie arabe*, in: Journal Asiatique, sér. 6, 11/1868/5-81, 109-253, 502-522, esp. pp. 139-143 (reprint in: Natural Sciences in Islam, vol. 31, Frankfurt 2001, pp. 179-422, esp. pp. 287-291).

yašb, yašm, yast
Jasper

10 pieces in various colours
Average diameter: 25 mm. Total weight: 68 g.
(Inventory No. K 3.22)

This is the stone called *ἴασπις λίθος* by the Greeks (Dioscorides, book 5, chapter 159, v. J. Berendes p. 551). Ibn al-Baiṭār mentions the stone in his *Ǧāmiʿ* (vol. 4, p. 209) and quotes from Dioscorides, Galen and al-Ġāfiqī. At the beginning he says, following Dioscorides: "Some claim that jasper is a kind of emerald. There is one variety whose colour comes close to that of smoke and represents as it were something covered by smoke. Another variety of jasper has white lustrous veins and is called Astrius (*kaukabī*). Another type is called Terebinthinum (*ṭarmīnūn*) because it has a colour similar to that of the fruit of the terpentine tree …" (transl. Sontheimer, vol. 2, p. 602, cf. transl. Leclerc, vol. 3, p. 427). Al-Bīrūnī mentions China (Ḫutan) as the deposit site; there since Antiquity various jasper varieties that were as pale as milk were preferred to diamonds, rubies or emeralds.

v. also Bīrūnī, *Ǧamāhir*, pp. 198-199; Muwaffaqaddīn al-Harawī, *Abniya*, pp. 120, 346 (transl. Achundow, pp. 190, 284, 318; reprint pp. 62, 156, 190).

ğins min al-ʿaqīq
Agate

(1) Broken.
Diameter: ca.135 mm, 0.69 kg.
(Inventory No. K 3.02 a)

(2) Sawed and polished.
Diameter: ca. 130 mm, 0.75 kg.
(Inventory No. K 3.02 b)

(3) Water Agate.
Diameter: 50 mm, 95 g.
(Inventory No. K 3.02 c)

This variety of carnelian is described in the pseudo-Aristotelian Book of Stones as follows: "Among the carnelians there are also those which are less beautiful, whose colour is that of meat water and in which there are fine white lines. Whosoever uses this variety as the stone for his seal, his anger will subside. It staunches haemorrhages and actually has its special effect on women whose menstrual period lasts too long. Its powder smoothens the teeth, removes dental caries and draws out the rotten blood from the roots of the teeth." (*Steinbuch des Aristoteles*, pp. 103,144, reprint op. cit., pp. 111,152).
This variety seems to be identical with that which al-Bīrūnī mentions in the *Kitāb al-Ğamāhir* (p. 174), following Naṣr b. Yaʿqūb al-Kindī (4th/10th cent.). It is said to have been called *ʿaqīq ḫalanğ* and to have been less valuable than carnelian. He mentions India as the deposit site.

v. also Tīfāšī, *Azhār al-afkār*, p. 34 (reprint op. cit., p. 27)..

2 Seals made of
Carnelian, see below, vol. V, 168
Iran, Zand/Qajar
(13th/18th-19th cent.)
Breadth: 17 and 20 mm.
(Inventory No. J 72 and 73)

ʿaqīq

(1) Yellow.
Diameter: 45 mm, 68 g.
(Inventory No. K 3.23a)

(2) Red.
90 x 60 mm, 340 g.
(Inventory No. K 3.23b)

This stone, which was especially popular in Arabia, occurs in various colours, but preference was given to that having a certain red shade which is called in Arabic *laun māʾ al-laḥm* ("meat-water colour"). This designation is explained by Ibn al-Baiṭār (*Ǧāmiʿ*, vol. 3, p. 128) as "the colour of the water that oozes when salt is sprinkled on meat". The Latin name carnelian goes back to this fact. Pliny calls the stone sardonyx. *ʿAqīq* was (and still is) used for necklaces, signet rings and inlaid work at prayer niches (*miḥrāb*) at mosques. It was also used as a powder for dental care. Arabic sources mention, among others, Yemen, the vicinity of Basra and the banks of river Jordan as the deposit sites.

Steinbuch des Aristoteles, pp. 103, 144–145 (reprint op. cit., pp. 111, 152–153); Tamīmī, *Muršid*, pp. 47–48, 151–152; Bīrūnī, *Ǧamāhir*, pp. 172–174; Qazwīnī, *ʿAǧāʾib al-maḫlūqāt*, pp. 230; J. Hell, in: EI[1], vol. 1, pp. 251.

ǧazʿ

Onyx

40 x 25 mm, 33 g.
(Inventory No. K 3.37)

This stone, quite well known in Arabia, is often mentioned together with the carnelian because of the deposit sites. Ibn al-Faqīh al-Hamaḏānī, the geographer who was active in the first half of the 4th/10th century (*Kitāb al-Buldān*, Leiden 1885, p. 36), after mentioning its source, goes on to say: "In the mountains of al-Yaman there are deposits of onyx (*ǧazʿ*); it has different varieties. All of them appear in the same places that carnelian occurs. The best and most valuable variety is *al-baqarānī*, others are *al-ʿarwānī*, *al-fārisī* (from Fars), *al-ḥabašī* (from Ethiopia), *al-muʿassal* (looking like honey), *al-muʿarraq* (having veins)."[1] Ibn al-Baiṭār (*Ǧāmiʿ*, vol. 1, p. 163) also knows a variety from China. Valuable information on this stone is to be found in the *Kitāb al-Išāra ilā maḥāsin at-tiǧāra* by Abu l-Faḍl ad-Dimašqī (p. 18): "Artists fashion large impeccable pieces of jewellery from it. Often they get high prices because of the skill they had to employ, since it is a stone that is difficult to work with. One of its varieties is the bāqarānī onyx. Signet rings are made out of it with the names of the kings and nobles. It fetches high prices." "Onyx consists of successive parallel layers, each having a clear white, black and red colour. With the help of these the artist carves out letters whose colour is different from that of the background. Sometimes three colours are also found, be it in writing or in a picture. Generally they can show three colours only in a picture because the picture is of the human body and can be carved through three layers; in the case of writing they can achieve that only when the surface of the signet ring is not flat (i.e. several colours are only possible when depictions are in relief)".[2]

v. also *Steinbuch des Aristoteles*, pp. 103, 145 (reprint op. cit. pp. 111, 153); Tīfāšī, *Azhār al-afkār,* pp. 35 (reprint op. cit. pp. 26); J.-J. Clément-Mullet, op. cit., pp. 162–170 (reprint in: Natural Sciences in Islam, vol. 31, Frankfurt 2001, pp. 310–318).

[1] E. Wiedemann, *Zur Mineralogie im Islam*, op. cit., p. 245 (reprint op. cit., p. 217).

[2] Translated by E. Wiedemann, op. cit., p. 235 (reprint op. cit., p. 207)

marqašītā (ḏahabīya)

85 x 65 mm, 482 g.
(Inventory No. K 3.32)

Marcasite (golden)

According to Šamsaddīn ad-Dimašqī (*Nuḫbat ad-dahr*, p. 84), there are seven varieties of marcasite of which he enumerates "the golden one" (*ḏahabī*), "the silver one" (*fiḍḍī*), "the copper one" (*nuḥāsī*), "the iron one" (*ḥadīdī*) and "the mercury one" (*zaibaqī*). The last two are said to be the lowest in quality. On the fundamental concept, most of the relevant Arabic sources refer to Dioscorides, who treats the πυρίτος λίθος in his fifth book (chapter 142). In his description from the point of view of medicine he does not mention the differences between the varieties. According to Julius Berendes (p. 545), Dioscorides confuses "two minerals, namely copper pyrite and sulphur pyrite".

Steinbuch des Aristoteles, pp. 112 (reprint op. cit. pp. 120); Rāzī, *al-Mudḫal at-taʿlīmī,* pp. 412 (reprint pp. 108); Ibn al-Baiṭār, *Ǧāmiʿ,* vol. 4, pp. 152–153 (French transl. Leclerc, vol. 3, pp. 312; German transl. Sontheimer, vol. 2, pp. 508–509); E. Wiedemann, *Zur Chemie bei den Arabern* (= Beiträge zur Geschichte der Naturwissenschaften XXIV), in: Sitzungsberichte der Physikalisch-medizinischen Sozietät (Erlangen) 43/1911/72–113, esp. pp. 97–98 (reprint in: Wiedemann, *Aufsätze*, vol. 1, pp. 689–730, esp. pp. 714–715).

Of the varieties of marcasite mentioned by Šamsaddīn ad-Dimašqī, we may also show here "the copper marcasite":

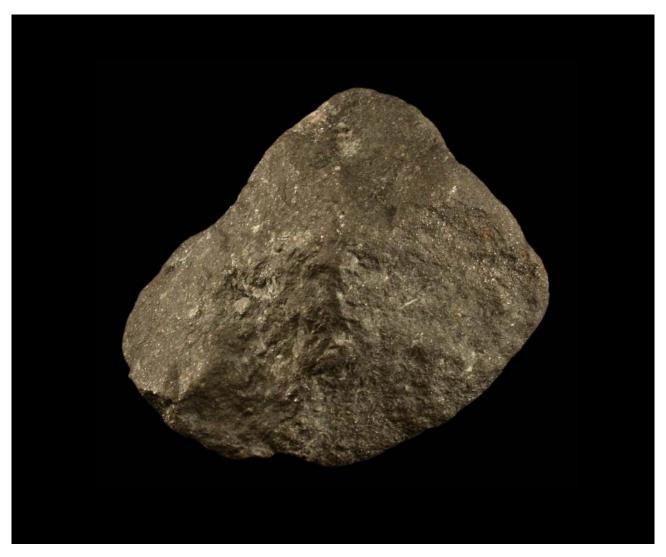
marqašītā nuḥāsīya

65 x 45, 185 g.
(Inventory No. K 3.28)

Copper Pyrite

As deposit sites of marcasite, ad-Dimašqī mentions Ḥadaṯ in Lebanon, Ǧūsīya near Karak, and Yaʿfūr, a village near Damascus.

šādanaǧ, amāṭīṭis

Hematite

(1) Var. haematite
Diameter: 60 mm, 0.3 kg.
(Inventory No. K 3.21a)

(2) Var. kidney ore
200 x 100 mm, 1.96 kg.
(Inventory No. K 3.21b)

This stone, called αἱματίτης by the Greek predecessors, appears in Arabic writings in the Arabic form *amāṭīṭis* as well as under the Persian equivalent *šādanaǧ* and also under the names *ḥaǧar ad-dam* ("blood stone") and *ḥaǧar aṭ-ṭūr* ("mountain stone"). at-Tamīmī (*Muršid*, pp. 65-69), to whom, as far as I know, we owe the most detailed treatment of the subject, says: "There are two varieties, one of them is masculine and the other feminine. The masculine haematite is the hard, smooth, externally very red variety that serves people (?) when it is rubbed on a red spot or a boil that is caused by a congestion in the face and in the head and in the other limbs; then it distributes the blood, removes the boil and is beneficial to the person; and that is why it is called blood stone. As for the feminine one, it is formed like a lentil, deep red and nice to the touch and (it looks) as if there are red lines in the form of a lentil on its surface. It is collected and melted (together) and glued one on the top of the other. It can be of different shades of deep red, and can be (differently) brittle when crushed. Those which are deep red and shine on the inside, when it breaks are chosen, which is clear from (other) rocks and which is easy to pulverise …" "Another variety is called blood stone from Yemen (*yamanī*); its colour comes close to black and it is not very hard. This is more useful to the eyes than the Nubian variety (*nūbī*). Another variety of Šādanaǧ is called that of Malaṭiya (*malaṭī*); yet another variety is imported from Libya, it is close to the Nubian variety in colour when heaped on top of each other …" (after the transl. by Jutta Schönfeld, ibid., pp. 66-68).
According to Arabic sources, the deposit sites are Malatya in Anatolia, the mountain of Tabor and al-Karak in Palestine and certain regions in Yemen, in Egypt, in Sudan and North Africa.

v. also Rāzī, *Asrār wa-sirr al-asrār*, pp. 4; *al-Rāzī's Buch Geheimnis der Geheimnisse*, pp. 45; Bīrūnī, *Ǧamāhir*, pp. 217; Ibn al-Baiṭār, *Ǧāmiʿ*, vol. 3, pp. 49–50 (French transl. Leclerc, t. 2, pp. 315; German transl. Sontheimer, vol. 2, pp. 77–78); Qazwīnī, *ʿAǧāʾib al-maḫlūqāt*, pp. 228; Tīfāšī, *Azhār al-afkār*, pp. 50 (reprint op. cit. pp. 11).

maġnāṭīs
Loadstone

70 x 55 mm, 0.35 kg.
(Inventory No. K 3.30)

The loadstone is also called *ḥağar al-bāhit* in Arabic. Knowledge of this mineral, which reached the Arabs from the Greek and other neighbouring cultures, was widespread in the Islamic world. The use of the loadstone in the ship's compass, which was at first rather primitive, reached the Arabic-Islamic culture area possibly from China. However, the further development of the compass and its systematic use as a means of orientation seems to have been an achievement of the nautical science which developed in the Indian Ocean region.[1]

[1] On this, v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 11, pp. 232-268.

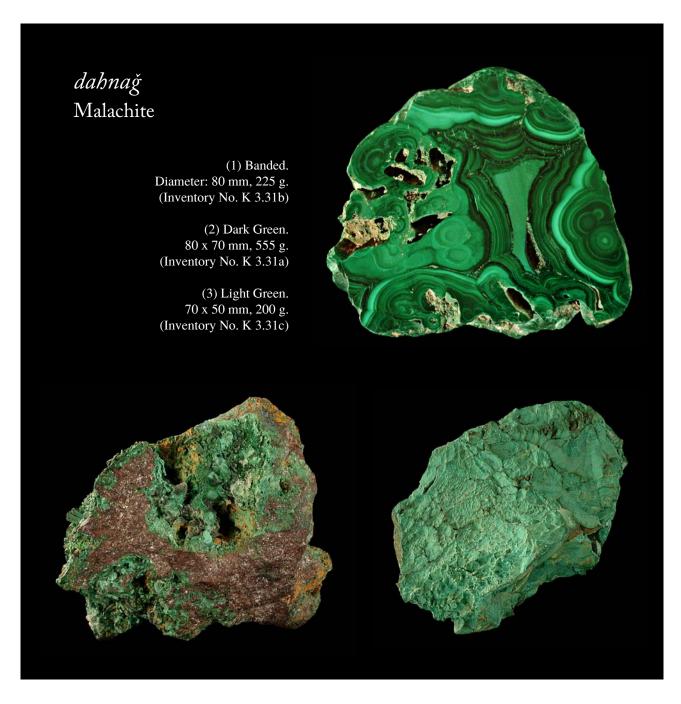
On the loadstone v. *Steinbuch des Aristoteles*, pp. 109, 154–155 (reprint op. cit., pp. 117, 162–163); Tamīmī, *Muršid,* pp. 123–128, 200–203; Bīrūnī, *Ğamāhir,* pp. 212–215; Qazwīnī, *ʿAğāʾib al-maḫlūqāt,* pp. 211–212, 239–240; Ibn al-Baiṭār, *Ğāmiʿ,* vol. 4, pp. 161 (French transl. Leclerc, vol. 3, p. 329–330; German transl. Sontheimer, vol. 2, pp. 523); Tīfāšī, *Azhār al-afkār,* pp. 37–39 (reprint op. cit., pp. 22–24); J.-J. Clément-Mullet, op. cit., pp. 170–178 (reprint in: Natural Sciences in Islam, vol. 31, pp. 318–326).

lāzuward

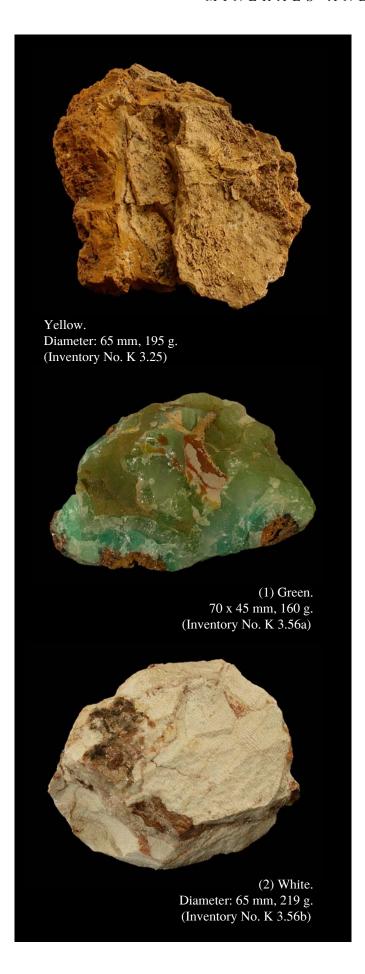
Lapis Lazuli, Lazurite

53 x 30 mm, 42 g.
(Inventory No. K 3.29)

According to ar-Rāzī, there is only one variety of lazurite. It is dark blue with a little red and has shining gold-coloured eyes (*al-Rāzī's Buch Geheimnis der Geheimnisse*, p. 86). Ar-Rāzī, who displays a sound knowledge of the subject here, describes the stone as one of four "oily" stones which have an oily lustre or which achieve special lustre when rubbed with oil (ibid, p. 44).
As a medicinal remedy lapis lazuli is used for diseases caused by black bile such as the symptoms of melancholy. About its function as a laxative at-Tamīmī (*Muršid*, pp. 77-78) says that he had tried it but "found no truth in it". In powder form the stone is one of the most important and most cherished pigments (true ultramarine) even today. Among the deposit sites, al-Bīrūnī (*Ǧamāhir*, p. 195) mentions a mine in the vicinity of the mountain Bīǧaḏī in Badaḫšān, in the extreme north-east of Afghanistan.

Steinbuch des Aristoteles, pp. 107, 153 (reprint op. cit., pp. 115, 161); Tamīmī, *Muršid,* pp. 75–78, 167–169; Qazwīnī, *'Aǧā'ib al-maḫlūqāt,* pp. 234; Ibn al-Baiṭār, *Ǧāmi',* vol. 4, pp. 91 (French transl. Leclerc, vol. 3, pp. 215–216; German transl. Sontheimer, vol. 2, pp. 410–411); J.-J. Clément-Mullet, op. cit., pp. 191–201 (reprint in: Natural Sciences in Islam, vol. 31, pp. 339–349).

fīrūzağ
Turquoise

108 x 56 mm, 376 g.
(Inventory No. K 3.53)

Turquoise is also called *ḥağar al-ġalaba* ("victory stone") and *ḥağar al-ʿain* ("eye stone"). In Arabic sources Nishapur and Gundishapur (South-East Iraq) are mentioned as the deposit sites.

Steinbuch des Aristoteles, pp. 106–107, 151–152 (reprint op. cit., pp. 114–115, 159–160); Rāzī, *Asrār wa-sirr al-asrār,* pp. 4; *al-Rāzī's Buch Geheimnis der Geheimnisse*, pp. 86; Tamīmī, *Muršid,* pp. 81–82, 173–174; Bīrūnī, *Ğamāhir,* pp. 169–172; Ibn al-Baiṭār, *Ğāmiʿ,* vol. 3, pp. 172 (French transl. Leclerc, vol. 3, S. 50–51; German transl. Sontheimer, vol. 2, pp. 270–271); Tīfāšī, *Azhār al-afkār,* pp. 32–33 (reprint op. cit., pp. 28–29); French transl., J.-J. Clément-Mullet, op. cit., pp. 150–157 (reprint in: Natural Sciences in Islam, vol. 31, pp. 298–305); Šamsaddīn ad-Dimašqī, *Tuḥfat ad-dahr,* pp. 68–69 (trad. franç., A.F. Mehren, pp. 78); Ibn al-Akfānī, *Nuḫab aḏ-ḏaḫāʾir*, pp. 761–762, cf. E. Wiedemann, *Zur Mineralogie im Islam*, pp. 225 (reprint op. cit., pp. 197–198).

dahnağ
Malachite

(1) Banded.
Diameter: 80 mm, 225 g.
(Inventory No. K 3.31b)

(2) Dark Green.
80 x 70 mm, 555 g.
(Inventory No. K 3.31a)

(3) Light Green.
70 x 50 mm, 200 g.
(Inventory No. K 3.31c)

According to the description by Arabic mineralogists, this green stone belongs to the minerals containing copper. Ar-Rāzī (*al-Rāzī's Buch Geheimnis der Geheimnisse*, p. 86) describes it as a green stone with veins out of which seals and amulets are carved. He knows of new and old malachites from Egypt, from Kirmān and from Ḫurāsān (Khorasan in north-eastern Persia). The old malachite from Kirmān was the best. Al-Bīrūnī (*Ǧamāhir* pp. 196-197) also mentions the high quality of malachite from Kirmān and refers to the mountain range Ḥarrat Banī Sulaim in the vicinity of Mecca as another deposit site.

In medicine the stone was credited with a certain antidotal effect. It was also used against leprosy and as a medicine for the eyes (Qazwīnī, *ʿAǧāʾib al-maḫlūqāt*, p. 225).

Steinbuch des Aristoteles, pp. 103–104, 145–147 (reprint op. cit., pp. 111–112, 153–155); Tamīmī, *Muršid,* pp. 117–122, 197–199; Ibn al-Baiṭār, *Ǧāmiʿ*, vol. 2, pp. 117–118 (French transl. Leclerc, vol. 2, pp. 132–133; German transl. Sontheimer, vol. 1, pp. 460–461); Tīfāšī, *Azhār al-afkār,* pp. 41–43 (reprint op. cit. pp. 18–20); French transl., J.-J. Clément-Mullet, op. cit., pp. 185–191 (reprint in: Natural Sciences in Islam, vol. 31, pp. 333–339).

Yellow.
Diameter: 65 mm, 195 g.
(Inventory No. K 3.25)

(1) Green.
70 x 45 mm, 160 g.
(Inventory No. K 3.56a)

(2) White.
Diameter: 65 mm, 219 g.
(Inventory No. K 3.56b)

tūtiyāʾ

Hemimorphite

The origin of the word is uncertain. It is assumed it could have derived either from the Persian or the Sanskrit. *Tūtiyāʾ* is counted among the stones. Arabic mineralogists knew it in white, yellow, green, brown and grey hues. In medicine it was used as a remedy for the eyes and against ulcers. The deposit sites mentioned are the coasts of the Indian Ocean, India (Sind), Persia (Kirmān), Mesopotamia (Baṣra), Eastern Anatolia (Armenia), Byzantium, Syria (Ḥimṣ), localities on the eastern coast of the Mediterranean (Beirut), in Northern Africa (Tūnis) and in Moorish Spain (al-Andalus).

Zinc Spar

Hemimorphite is usually "accompanied by another zinc-containing mineral, viz. zinc carbonate, which as a mineral is named zinc spar or calamine and plays an important role as zinc ore. It is to be found at times also in bright green, blue and probably also in violet-coloured aggregates just like hemimorphite …" (Bauer, *Edelsteinkunde*, p. 524).

v. Rāzī, *Asrār wa-sirr al-asrār,* p. 2 (*al-Rāzī's Buch Geheimnis der Geheimnisse*, pp. 44, 86); idem, *al-Mudḫal at-taʿlīmī,* pp. 413–414 (reprint pp. 109–110; Rāzī states here that he discussed the origin of this material in his book *ʿIlal al-maʿādin*); *Steinbuch des Aristoteles*, pp. 175–176 (reprint op. cit. pp. 183–184); Tamīmī, *Muršid,* pp. 53–66, 158–162; Qazwīnī, *ʿAǧāʾib al-maḫlūqāt* pp. 214; Ibn al-Baiṭār, *Ǧāmiʿ*, vol. 1, pp. 143–145 (French transl. Leclerc, vol. 1, pp. 322-325; German transl. Sontheimer, vol. 1, pp. 217–220).

bādzahr

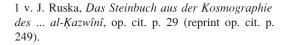
Bezoar Stone,

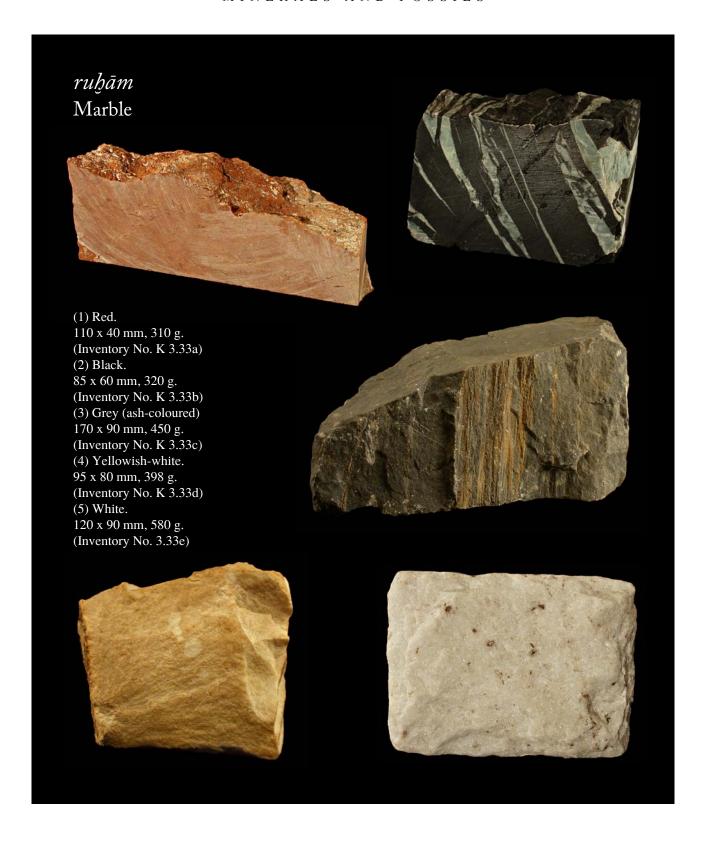
or perhaps:

ḥağar al-ḥaiya

(‹Snake Stone›)

Serpentine

(1) Green.
120 x 90 mm, 478 g.
(Inventory No. K. 3.47a)

(2) Grey.
100 x 45 mm, 242 g.
(Inventory No. K 3.47b)

(3) Black.
100 x 70 mm, 375 g.
(Inventory No. K 3.47c)

According to al-Qazwīnī (*ʿAǧāʿib al-maḫlūqāt*, p. 217), the two stones are confused with one another. The name of the first is derived from the Persian (*zahr* = poison).[1] Both were used as antidotes. They are also said to be useful against leprosy and the diseases of the heart, the kidneys and the stomach.
Persia, especially Ḫurāsān (Khorasan) and India are mentioned as deposit sites.

Dioscoride, Livre 5, chap. 161 (v. J. Berendes, p. 55); *Steinbuch des Aristoteles*, pp. 104–105, 147–149 (reprint op. cit., pp. 112–113, 155–157); Tamīmī, *Muršid,* pp. 115–118, 194–197; Bīrūnī, *Ǧamāhir,* pp. 200–202, 207–208; Qazwīnī, *ʿAǧāʾib al-maḫlūqāt,* pp. 217–218, 231; Ibn al-Baiṭār, *Ǧāmiʿ,* vol. 2, p. 10 (trad. franç., Leclerc, vol. 1, p. 412; German transl. Sontheimer, vol. 1, p. 289).

1 v. J. Ruska, *Das Steinbuch aus der Kosmographie des ... al-Ḳazwînî*, op. cit. p. 29 (reprint op. cit. p. 249).

ruḫām
Marble

(1) Red.
110 x 40 mm, 310 g.
(Inventory No. K 3.33a)
(2) Black.
85 x 60 mm, 320 g.
(Inventory No. K 3.33b)
(3) Grey (ash-coloured)
170 x 90 mm, 450 g.
(Inventory No. K 3.33c)
(4) Yellowish-white.
95 x 80 mm, 398 g.
(Inventory No. K 3.33d)
(5) White.
120 x 90 mm, 580 g.
(Inventory No. 3.33e)

In Persian and Turkish the stone is called mermer. The Arabic sources in which it is described know it in various shades and mention that it is used for building and as a tombstone. In Arabic medicine it was used as styptic in pulverised form.

Idrīsī, *al-Ǧāmiʿ li-ṣifāt aštāt an-nabāt*, vol. 2, 2nd part, p. 452; Ibn al-Baiṭār, *Ǧāmiʿ*, vol. 2, p. 138 (French transl. Leclerc, vol. 2, p. 1040; German transl. Sontheimer, vol. 1, p. 493); Qazwīnī, *ʿAǧāʾib al-maḫlūqāt*, p. 225.

artakān

Yellow Iron Ore, Ochre

75 x 55 mm, 215 g.
(Inventory No. K 3.15)

A yellow brittle stone which has been used as a pigment since the Palaeolithic period and which serves in the medical field for the treatment of skin diseases.

Ibn al-Baiṭār, *Ǧāmiʿ*, vol. 1, pp. 20–21 (French transl. Leclerc, vol. 1, p. 49–50; German transl. Sontheimer, vol. 1, p. 28).

maġnīsiyā
Pyrolusite

(1) diameter: 55 mm, 142 g.
(Inventory No. K 3.41 a)

(2) diameter: 70 mm, 210 g.
(Inventory No. K 3.41 b)

The stone *maġnīsiyā*, which was known in numerous colours, is often mentioned in Arabic sources together with marqašīṯa, the marcasite, which was likewise known in many colours. That is why they were quite frequently mistaken for one another.[1]
About *maġnīsiyā*, Abū Bakr ar-Rāzī states as follows: "There are different varieties (colours). There is one earthy black variety in which there are shining eyes. Then there are also hard iron-like pieces of it; that is the masculine variety. Then there is a red variety with crust; that is the feminine variety; in it there are flashing eyes and it is the best of its kind."[2] J. Ruska says in explanation: "The word maġnīsiyā refers in Rāzī's work on the manganese oxides which even now are differentiated for practical purposes as soft and hard manganese ores. With 'flashing eyes' he probably means small areas of crystal which flash in the sun while they moved to and fro and perhaps he also means areas shining like metal against a dull background. The red variety which appears in the form of a crust is obviously manganese spar which is to be found often at manganese sites as a product of transformation. The differentiation of the various varieties leads us to assume that Rāzī was familiar with a natural site in Persia."[3]
With great probability *maġnīsiyā* is identical with the mineral which in our times is called pyrolusite. It was used for the manufacture of glass. Deposit site is Persia.

See also *Steinbuch des Aristoteles*, op. cit., p. 112, 160-161 (reprint op. cit., p. 120, 160-161); Abū ʿAbdallāh al-Ḫwārizmī, *Mafātīḥ al-ʿulūm*, p. 261; Ibn al-Baiṭār, *Ǧāmiʿ*, vol. 4, p. 161 (French transl. Leclerc, vol. 3, p. 329; German transl. Sontheimer, vol. 2, p. 523).

[1] v. E. Wiedemann, *Zur Chemie bei den Arabern* (= Beiträge zur Geschichte der Naturwissenschaften XXIV), in: Sitzungsberichte der Physikalisch-medizinischen Sozietät (Erlangen) 43/1911/72-113, esp. p. 98 (reprint in: Wiedemann, *Aufsätze*, vol. 1, pp. 689-730, esp. p. 715).
[2] Translated by J. Ruska, *Al-Rāzī's Buch Geheimnis der Geheimnisse*, op. cit., p. 86.
[3] ibid, p. 43; v. also p. 146 about the two methods of calcination of *maġnīsiya*.

(1) Closed.
Diameter: 50 mm, 74 g.
(Inventory No. K 3.01a)

(2) Broken.
Diameter: 50 mm, 66 g.
(Inventory No. K 3.01b)

ḥaǧar al-ʿuqāb
Eagle Stone, Rattle Stone

"A stone that resembles the Tamarind seed; when it is shaken a sound is heard from inside, (but) when it is broken, nothing is seen in it. It is found in the nest of the eagle that brings it from India. When somebody goes towards the nest, it [the eagle] takes it [the stone] and throws it towards him so that he may take it and turn back, as if the eagle knew that he came in search of this stone."[1] The stone is also called *ḥaǧar an-nasr* ("eagle stone") and *ḥaǧar iktamakt*.
Four deposit sites are mentioned: Yemen, Antioch, Cyprus and Northern Africa.

Ibn al-Baiṭār, *Ǧāmiʿ*, vol. 1, pp. 51–52, vol. 2, p. 12 (French transl. Leclerc, vol. 1, pp. 121–122, 412, 420–421; German transl. Sontheimer, vol. 1, pp. 73–74, 294); v. also Bīrūnī, *Ǧamāhir*, p. 102.

[1] Qazwīnī, *ʿAǧāʾib al-maḫlūqāt*, p. 220, transl. J. Ruska, *Das Steinbuch aus der Kosmographie des ... al-Ḳazwînî*, op. cit. p. 218 (reprint op. cit., p. 238).

šabb

Alum

2 specimens.
Diameter: 24 mm.
Total weight: 60 ct.
(Inventory No. K 3.03)

According to ar-Rāzī, alum belongs to the group of vitriols. These are used in dyeing and tanning, as additives to coloured inks and for clarifying turbid liquids. In the field of medicine, they have their use as styptics, as ingredients of eye medicines and of collyria, in skin diseases, as gargling water for toothaches and for fortifying the gums.
Deposit sites are Egypt, Libya, Yemen and Eastern Turkistan.

Steinbuch des Aristoteles, pp. 119, 174 (reprint op. cit., pp. 127, 182); Rāzī, *Asrār wa-sirr al-asrār,* pp. 2, 4; *al-Rāzī's Buch Geheimnis der Geheimnisse*, p. 87; J. Ruska, *Das Buch der Alaune und Salze*, Berlin 1935, pp. 79–80, 121.

Ar-Rāzī speaks of seven types of vitriols, among them *qalqadīs*, *qalqaṭār*, *qalqand* and *sūrīn*. Other scholars like Ibn Sīnā and Ibn al-Baiṭār mention the colours white, yellow, red and green; blue is missing. Ar-Rāzī also deals with procedures for the artificial production of vitriols (v. *Al-Rāzī's Buch Geheimnis der Geheimnisse*, op. cit., pp. 47, 87-88; Ibn al-Baiṭār, *Ǧāmiʿ*, vol. 2, pp. 148-152).
According to Arabic sources, the deposit sites are Syria, Egypt, Yemen, Cyprus, Spain as well as Ǧurǧān und Ṭabaristān in Northern Persia and Bāmiyān in present-day Afghanistan.
The medicinal use of the stone is mentioned in the case of ulcers, accumulation of earwax, ranula and decay in the mouth and nose, against scabies and for staunching blood (Ibn al-Baiṭār, *Ǧāmiʿ*, vol. 2, p. 152; French transl. Leclerc, vol. 2, p. 194; German transl. Sontheimer, vol. 1, p. 515).

(1) White.
2 pieces, ∅: 30 mm, 13 g.
1 piece, ∅: 50 mm, 34 g.
(Inventory No. K 3.54a)

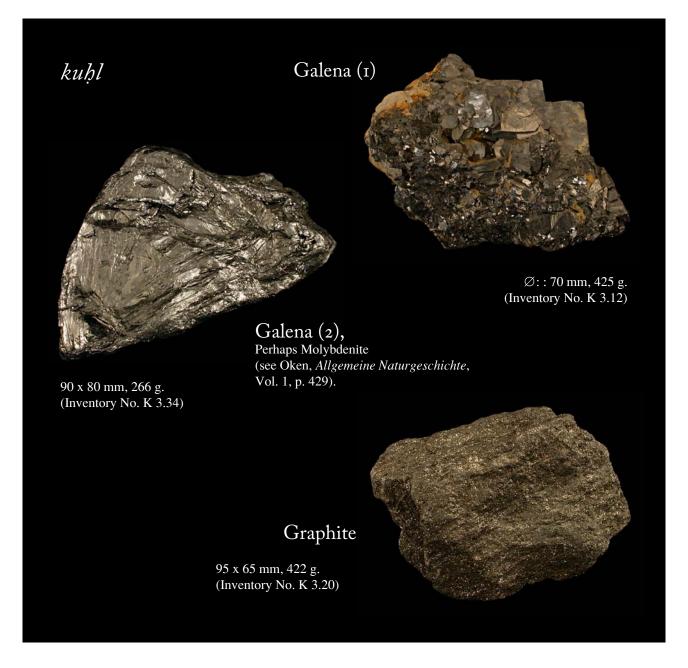
(2) Coloured Vitriol
96 x 63 mm, 55 g.
(Inventory No. K 3.54c)

(3) Blue.
Length: 58 mm, 28 g.
(Inventory No. 3.54b)

(4) Green.
Ground. 13 g.
(Inventory No. 3.54d)

(5) Golden Eyes.
∅: 42 mm, 18 g.
(Inventory No. K 3.54e)

(6) Chalcanthite (copper vitriol).
∅: 46 mm, 51 g.
(Inventory No. K 3.59)

v. also *Steinbuch des Aristoteles*, op. cit., pp. 119, 173–174 (reprint op. cit., pp. 127, 181–182); Bīrūnī, *Ǧamāhir*, pp. 253; Idrīsī, *al-Ǧāmiʿ li-ṣifāt aštāt an-nabāt*, vol. 1, p. 152, vol. 1, part 2, pp. 209–211; Qazwīnī, *ʿAǧāʾib al-maḫlūqāt*, pp. 225–226, cf. J. Ruska, *Das Steinbuch aus der Kosmographie des… al-Ḳazwînî*, op. cit., pp. 23–24 (reprint op. cit. pp. 243–244).

iṯmid

Antimony

∅: ca. 45 mm, 122 g.
(Inventory No. K 3.05)

According to Muḥammad b. Aḥmad at-Tamīmī (4th/10th cent.), there are two kinds of antimony. One comes from the region of Isfahan, the other from the Maġrib. Of the latter he knows again two kinds (*Kitāb al-Muršid,* pp. 31–35).

Steinbuch des Aristoteles, pp. 119, 175 (reprint pp. 127, 183); Ibn al-Ǧazzār, *Iʿtimād*, facsimile ed., pp. 177–178, trad. Lat. *Liber fiduciæ,* pp. 89 (reprint op. cit., pp. 331); Ibn al-Baiṭār, *Ǧāmiʿ,* vol. 1, pp. 12 (French transl. Leclerc, vol. 1, pp. 27–28; German transl. Sontheimer, vol. 1, pp. 15–16).

kuḥl

Galena (1)

∅: : 70 mm, 425 g.
(Inventory No. K 3.12)

Galena (2),
Perhaps Molybdenite
(see Oken, *Allgemeine Naturgeschichte*,
Vol. 1, p. 429).

90 x 80 mm, 266 g.
(Inventory No. K 3.34)

Graphite

95 x 65 mm, 422 g.
(Inventory No. K 3.20)

In Arabic literature galena is not clearly differentiated from antimony (*iṯmid*), which is listed above (p. 193). Frequently both terms are used as synonyms. The most detailed and best treatment of the subject can be attributed to the *Kitāb al-Muršid* by Muḥammad b. Aḥmad at-Tamīmī (pp. 31-36). A valuable commentary on it with additional references to further sources is published by Jutta Schönfeld (ibid., pp. 132-137). Among the characteristics of galena, Lorenz Oken[1] mentions its metallic sheen and its funnel-shaped cavities which at-Tamīmī obviously refers to as "*muʿayyan* (endowed with eyes); the flatter these 'eyes' are, that is to say the smoother the surface, the better the quality of Galena" (ibid., p. 133).

As deposit sites, Arabic sources mention Moorish Spain (al-Andalus), North Africa (Tunesia) and Persia. In this connection, the two mountains Ǧabal Zaġwān near Tunis (v. Yāqūt, *Muʿǧam al-buldān*, vol. 2, p. 935) and Ǧabal al-Kuḥl near the Spanish town of Baza (Qazwīnī, *ʿAǧāʾib al-maḫlūqāt*, p. 171) are mentioned by name (v. ibid., p. 134). Furthermore, the eye make-up, or rather the fine powder used in its production which is made from, graphite for example, is called kuhl in its generic sense.

[1] *Allgemeine Naturgeschichte für alle Stände*, vol. 1: *Mineralogie und Geognosie*, Stuttgart 1839, pp. 426, 435.

zaibaq
Mercury

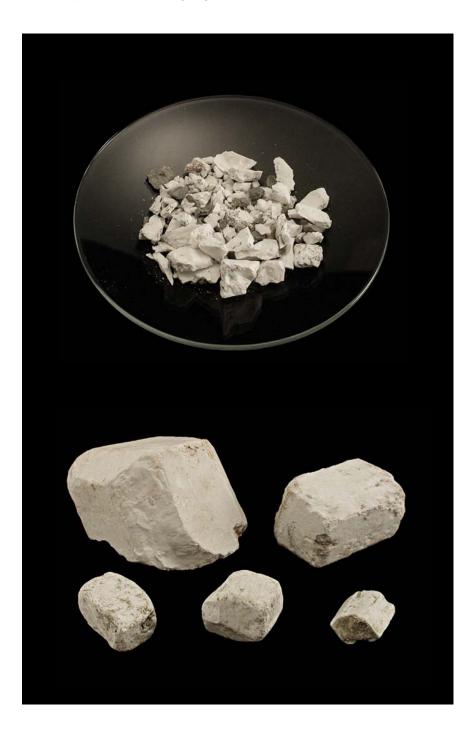
ca. 15 g. in a welded ampoule
(Liquid at room temperature)
(Inventory No. K 3.43)

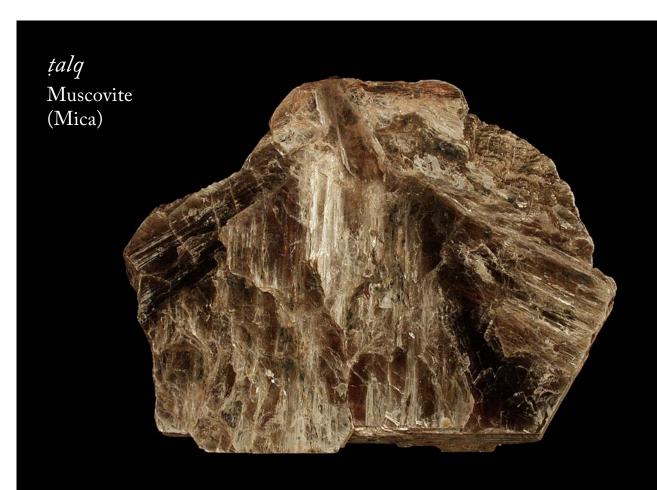
Ǧābir b. Ḥaiyān, ar-Rāzī and most Arabic chemist-alchemists count mercury among the "spirits" (*arwāḥ*). The word *zaibaq* goes back to a Middle Persian word which reached the Syriac and the Arabic language.[1] As deposit sites, Arabic sources mention Iṣṭaḫr near Persepolis, another site in Azerbaijan, south-east of Lake Urmia and a region in the mountains of Bāmiyān in the west of the Hindukush.[2]

Steinbuch des Aristoteles, op. cit., pp. 123, 180 (reprint op. cit., pp. 131, 188); Rāzī, *Asrār wa-sirr al-asrār,* pp. 13–20; Bīrūnī, *Ǧamāhir,* pp. 229–232; Qazwīnī, *Āṯār al-bilād,* p. 126 (v. Dārābǧird); Ibn al-Baiṭār, *Ǧāmiʿ,* vol. 2, pp. 177–178 (French transl. Leclerc, vol. 2, pp. 228–230; German transl. Sontheimer, vol. 1, pp. 553–555).

zunǧufr
Cinnabarite (Cinnabar)

Dimension: 120 x 180 mm.
Weight: 160 g.
Poisonous!
(Inventory No. K 3.57)

Apart from the cinnabar (*zunǧufr maḫlūq*) extracted from mines, artificially produced cinnabar (*zunǧufr maṣnūʿ*) was also known in the 4th/10th century. The most famous deposit site was Spain (v. Ibn al-Baiṭār, *Ǧāmiʿ*, vol. 2, p. 170; J. Ruska, *al-Rāzī's Buch Geheimnis der Geheimnisse*, op. cit., pp. 38-51).
In medicine, cinnabar was one of the ingredients in ointments for injuries and was used as a powder in the treatment of ulcers.

Steinbuch des Aristoteles, pp. 124–125, 182 (reprint op. cit., pp. 132–133, 190); Qazwīnī, *ʿAǧāʾib al-maḫlūqāt,* p. 228; French transl. Leclerc, vol. 2, pp. 221–222.

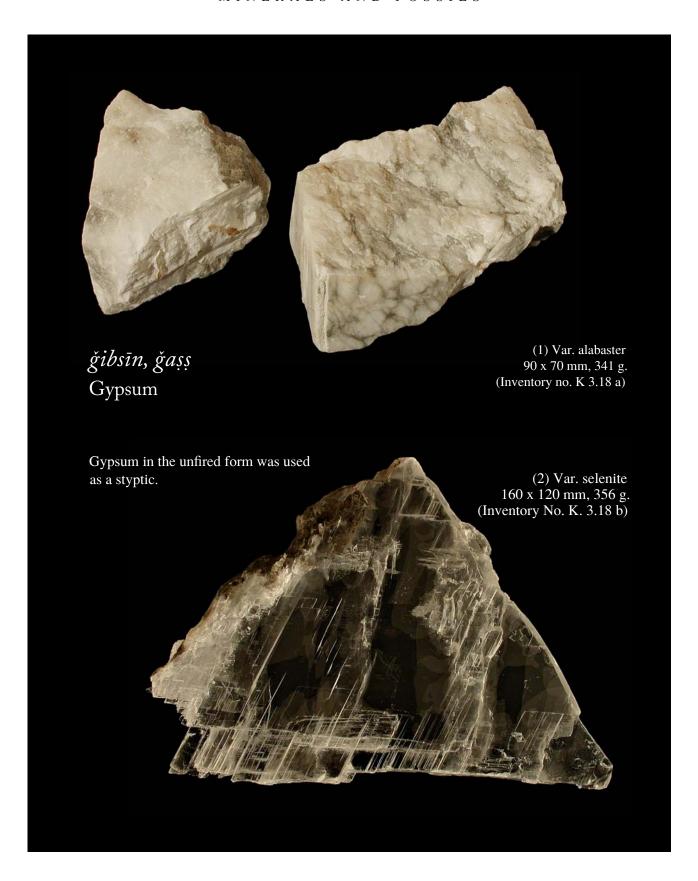
[1] v. J. Ruska, *al-Rāzī's Buch Geheimnis der Geheimnisse*, op. cit., p. 37.
[2] Ibid., pp. 38.

būraq
Borax

(1) Coarse, broken.
Weight: 11 g.
(Inventory No. K 3.13a)

(2) Idiomorphic
50 x 40 mm, 65 g.
(Inventory No. K 3.13b)

Arabic mineralogists and chemists sometimes treat *būraq* (borax) and *tinkār* (tinkal) as two separate substances and at other times as a single one. Abū Bakr ar-Rāzī seems to be of the opinion that tinkal is produced artificially from borax and that borax was known in five colours. The "borax of the bread" (*būraq al-ḫubz*) and the "borax of the goldsmiths" (*būraq aṣ-ṣinā'a*) was white. The best variety he continues, was the "borax from Zarāwand" in Persia. Al-Qazwīnī (*'Aǧā'ib al-maḫlūqāt* p. 212) mentions India and Kerman in Persia as the deposit sites.

v. also Rāzī, *Asrār wa-sirr al-asrār,* p. 6; *al-Rāzī's Buch Geheimnis der Geheimnisse*, op. cit., pp. 88-89; *Steinbuch des Aristoteles*, op. cit., pp. 118, 173 (repr. pp. 126, 181); Tamīmī, *Muršid,* pp. 51–53, 155–157; Ibn al-Baiṭār, *Ǧāmi',* vol. 1, pp. 125–127, 141 (French transl. Leclerc, vol. 1, pp. 288–290; German transl. Sontheimer, vol. 1, pp. 187–190).

ṭalq
Muscovite (Mica)

The German word 'Talk', which designates a variety of gypsum, is derived from the Arabic term *ṭalq*.
In medical science *ṭalq* was used against ulcers and as a styptic.
As deposit sites, Arabic sources mention India, Yemen, Spain and Cyprus.

175 x 135 mm, 0.69 kg.
(Inventory No. K 3.35)

Steinbuch des Aristoteles, pp. 119, 174–175 (reprint op. cit., pp. 127, 182–183); Rāzī, *al-Mudḫal at-taʿlīmī,* p. 413 (reprint p. 109); Idrīsī, *al-Ǧāmiʿ li-ṣifāt aštāt an-nabāt*, vol. 2, part 1, p. 243; Qazwīnī, *ʿAǧāʾib al-maḫlūqāt,* p. 230; Tīfāšī, *Azhār al-afkār,* pp. 54–55 (reprint op. cit., pp. 6–7); J.-J. Clément-Mullet, op. cit., pp. 237–250 (reprint in: Natural Sciences in Islam, vol. 31, pp. 385–398).

milḥ
Rock Salt

(1) Idiomorphic.
Diameter: 75 mm, 185 g.
(Inventory No. K 3.51

(2) Coarse.
120 x 80 mm, 0.5 kg.
(Inventory No. K 3.51a)

ʿAlī b. Rabban aṭ-Ṭabarī, *Firdaus al-ḥikma*, p. 395; Rāzī, *Asrār wa-sirr al-asrār,* pp. 6–7; idem, *Ḥāwī*, vol. 21, part 2, Hyderabad 1968, pp. 554–561; Muwaffaqaddīn al-Harawī, *Abniya,* pp. 314–315 (Transl. Achundow, p. 272; repr. p. 144); Abū ʿAbdallāh al-Ḫwārizmī, *Mafātīḥ al-ʿulūm,* p. 259; Ibn al-Baiṭār, *Ǧāmiʿ,* vol. 4, p. 163–166 (French transl., Leclerc, vol. 3, pp. 334–337; German transl. Sontheimer, vol. 2, pp. 527–531); Qazwīnī, *ʿAǧāʾib al-maḫlūqāt,* p. 240.
E. Wiedemann, *Entsalzung des Meerwassers bei Bîrûnî*, in: Chemiker-Zeitung 46/1922/230 (reprint in: *Gesammelte Schriften*, vol. 2, Frankfurt 1984, p. 1019); J. Ruska, *Das Buch der Alaune und Salze*, Berlin 1935..

ğibsīn, ğaṣṣ
Gypsum

(1) Var. alabaster
90 x 70 mm, 341 g.
(Inventory no. K 3.18 a)

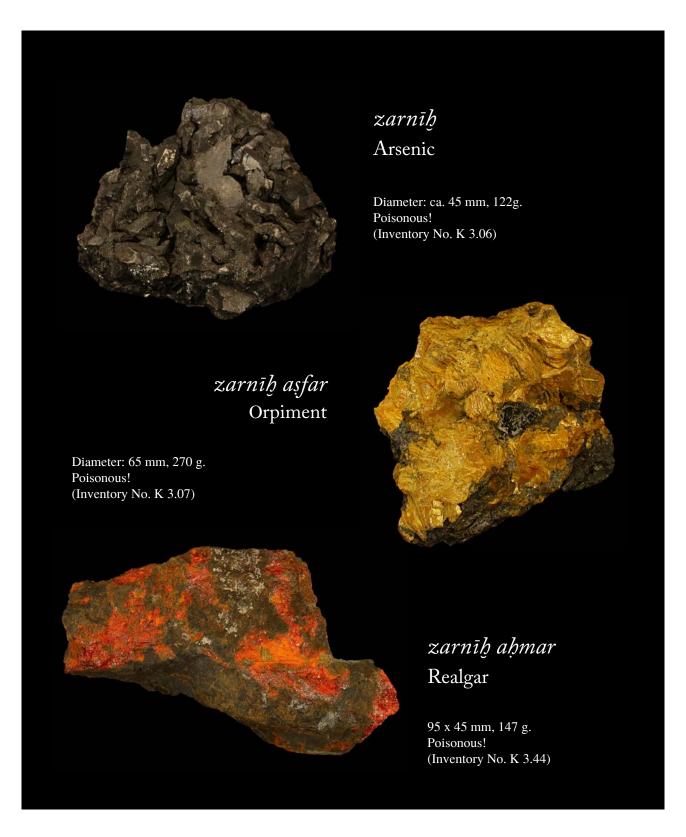
Gypsum in the unfired form was used as a styptic.

(2) Var. selenite
160 x 120 mm, 356 g.
(Inventory No. K. 3.18 b)

Rāzī, *Asrār wa-sirr al-asrār,* p. 4; *al-Rāzī's Buch Geheimnis der Geheimnisse*, p. 87; Ibn al-Baiṭār, *Ğāmiʿ,* vol. 1, p. 159 (French transl., Leclerc, vol. 1, pp. 346–347; German transl. Sontheimer, vol. 1, pp. 242–243).

kibrīt
Sulphur

(1) Fine crystalline.
65 x 55 mm, 9 g.
(Inventory No. K 3.45a)

(2) Coarse crystalline.
55 x 50 mm, 88 g.
(Inventory No. K 3.45b)

Arab chemist-alchemists enumerate sulphur among the "spirits" (*arwāḥ*) as against metals, which they call "bodies" (*ağsād*). In contrast to the bodies, the spirits are "colouring" and "volatile". Arab chemists and mineralogists know sulphur in various colours, among them yellow, red, white and black hues. They considered red sulphur to be the most valuable. Sulphur was an indispensable element in chemical and industrial processes. According to ar-Rāzī, the substances with which sulphur and *zarnīḫ* (see below) were treated included "chrysocolla, nūra, limes, the filings of iron, of copper, of tin and of black lead, vitriol, salt, white lead, litharge, glass, potash, talcum …"[1] In a joint study Eilhard Wiedemann and Julius Ruska found twenty names for sulphur when they attempted to compile the code names commonly used by Arabic alchemists. These names were predominantly Arabic, rarely Persian or Syrian and hardly ever Greek.[2] In the medical field the use of sulphur was very widespread, for instance, for the treatment of scabies, jaundice, asthma and coughs, in the case of maculae or scorpion stings.

Steinbuch des Aristoteles, pp. 112–113, 161–162 (reprint op. cit., pp. 120–121, 169–170); Ibn al-Baiṭār, *Ğāmiʿ*, vol. 4, pp. 49–50 (French transl., Leclerc, vol. 3, pp. 139–141; German transl. Sontheimer, vol. 2, pp. 344–347); Qazwīnī, *ʿAğāʾib al-maḫlūqāt*, pp. 243–244; Šamsaddīn ad-Dimašqī, *Tuḥfat ad-dahr*, p. 58 (trad. A.F. Mehren, pp. 62–63).

[1] J. Ruska, *al-Rāzī's Buch Geheimnis der Geheimnisse*, op. cit., p. 111.
[2] *Alchemistische Decknamen*, in: Sitzungsberichte der Physikalisch-medizinischen Sozietät (Erlangen) 56–57/1924–25/17–36, esp. pp. 35–36 (reprint in: Wiedemann, *Aufsätze*, vol. 2, pp. 596–615, esp. pp. 614–615).

zarnīḫ
Arsenic

Diameter: ca. 45 mm, 122g.
Poisonous!
(Inventory No. K 3.06)

zarnīḫ aṣfar
Orpiment

Diameter: 65 mm, 270 g.
Poisonous!
(Inventory No. K 3.07)

zarnīḫ aḥmar
Realgar

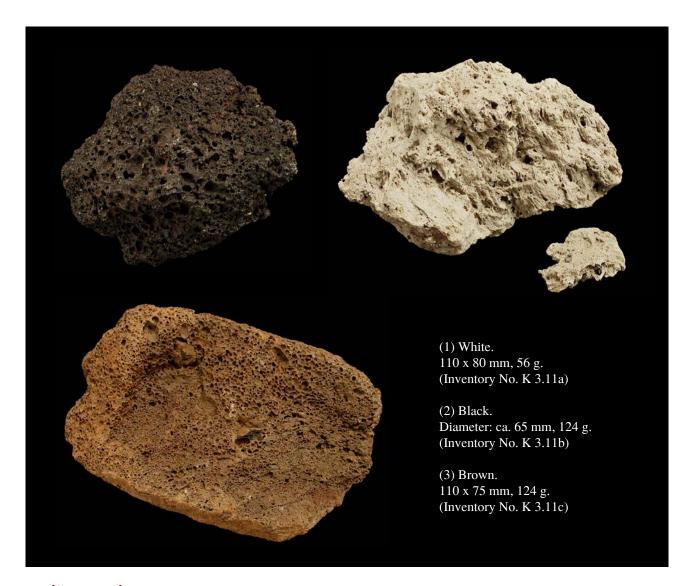
95 x 45 mm, 147 g.
Poisonous!
(Inventory No. K 3.44)

Arab mineralogists knew arsenic in several colours. They also knew its use as a poison. They mention Iṣfahān as the deposit site.

Steinbuch des Aristoteles, op. cit., p. 113; Rāzī, *Asrār wa-sirr al-asrār*, p. 3; Bīrūnī, *Ǧamāhir*, p. 103; Ibn al-Baiṭār, *Ǧāmiʿ*, vol. 2, pp. 160-161 (he cites, among others, ar-Rāzī's *Kitāb ʿIlal al-maʿādin*, which is not extant) (French transl. Leclerc, vol. 2, pp. 205-207; German transl. Sontheimer, vol. 1, pp.

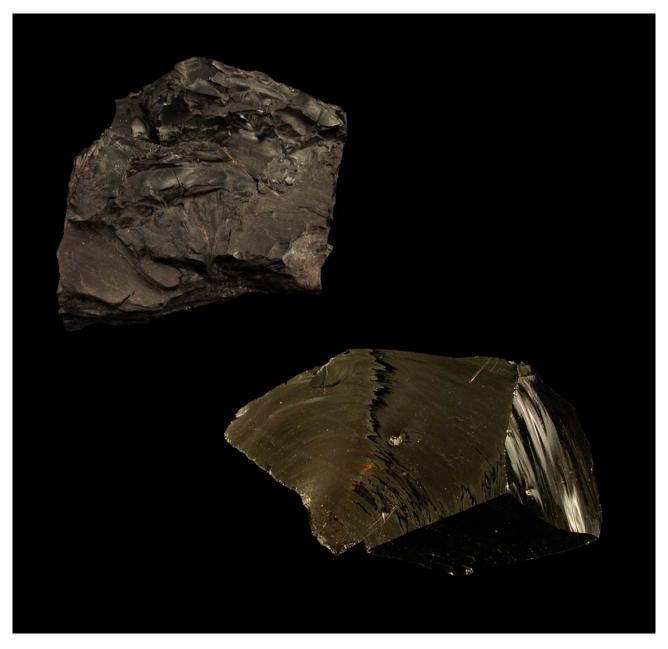
ḥaǧar al-birām
Steatite

105 x 60 mm, 225 g.
(Inventory No. K 3.50)

Arab philologists refer to this mineral extracted from mines as “the quintessential pot” (*al-qidr muṭlaqan*), since it is especially suitable for the production of vessels, coal basins, lamps etc. Ḥiǧāz (Western Arabia) and Yemen were the most well-known deposit sites.[1] The geographer aš-Šarīf al-Idrīsī[2] calls the locality al-Ḥaurāʾ on the east coast of the Red Sea the most important deposit site from where it was exported to many countries. A mine for this mineral (*maʿdin al-burm*) located near a village of the same name situated between aṭ-Ṭāʾif and Mecca was already known in Umayyad times.[3] Al-Qazwīnī[4] also mentions Ṭūs in north-eastern Persia as a well-known deposit site. According to Ibn al-Baiṭār (*Ǧāmiʿ*, vol. 2, p. 10), the pulverized stone was used for dental care, and also–according to ar-Rāzī–as an ingredient of ‘artificial loam’, which was indispensable in the chemical laboratories of those times (see above, p. 134).[5]

[1] Ibn Manẓūr, Muḥammad b. Mukarram, *Lisān al-ʿarab*, vol. 14, Cairo 1302 (1885), p. 311.
[2] *Nuzhat al-muštāq fī ḫtirāq al-āfāq*, Naples and Rome 1970, p. 350.
[3] Cf. Yāqūt, *Muʿǧam al-buldān,* vol. 4, p. 572.
[4] *Āṯār al-bilād,* p. 275.
[5] *Al-Rāzī’s Buch Geheimnis der Geheimnisse*, pp. 61, 96, 195; E. Wiedemann, *Zur Mineralogie im Islam*, p. 251 (reprint op. cit., p. 223).

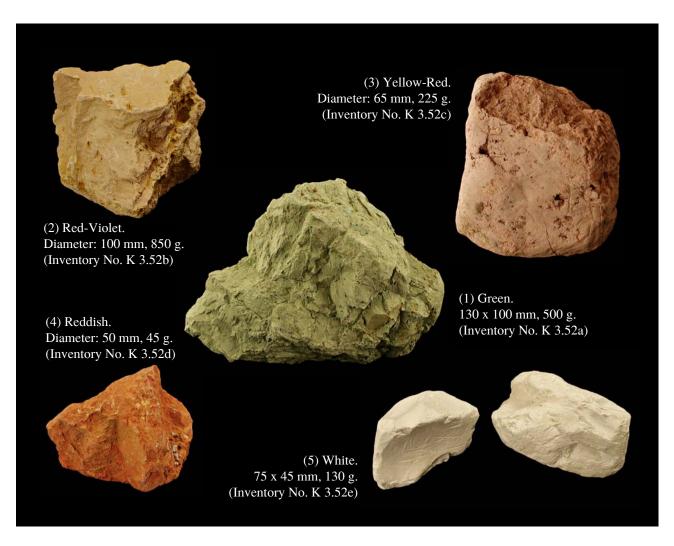
(1) White.
110 x 80 mm, 56 g.
(Inventory No. K 3.11a)

(2) Black.
Diameter: ca. 65 mm, 124 g.
(Inventory No. K 3.11b)

(3) Brown.
110 x 75 mm, 124 g.
(Inventory No. K 3.11c)

qaišūr, qaisūr
Pumice

In the pseudo-Aristotelian book of stones (p. 120, reprint p. 128) pumice is described as follows: “This is a stone of the ocean, light, of loose substance; it swims on water. It is found in Sicily, it is mostly white and is called sea-butter. When animal hides are rubbed with it, they become rough. It cleanses the teeth and is included in powders for the eyes. With pumice it is also possible to remove colour and ink from paper. — It removes the leucoma from the eye, particularly from the eyes of animals, when (the veterinarian) mixes it with honey. But he does not apply it in pure form, because it would hurt the animal due to its causticity” (after the transl. by J. Ruska, p. 176, reprint p. 184). Arabic sources mention Armenia and Alexandria, besides Sicily, as the deposit sites. Tamīmī (*Muršid*, pp. 91-95) says: ” As for its true composition, it is one of the burnt ashes; because the fire that occurs in Sicily on the mountain which lies on the sea and which is called volcano, spits this stone out, big rocks and small ones, and that stone is of the nature of fire. When it falls into the water of the sea, it swims on the surface of the water, because in its body there is porosity and brittleness” (after the transl. by Jutta Schönfeld, op. cit., p. 92).

v. also Qazwīnī, *ʿAǧāʾib al-maḫlūqāt*, p. 233; Ibn al-Baiṭār, *Ǧāmiʿ*, vol. 4, p. 42 (French transl., Leclerc, vol. 3, p. 126; German transl. Sontheimer, vol. 2, pp. 332–333).

sabağ
Jet

(1) Diameter: 90 mm, 188 g.
(Inventory No. K 3.17)

(2) 64 x 116 mm.
(Inventory No. K 3.38)

Pitch coal or jet is a bituminous lignite. The Arabic name *sabağ* comes from the Middle Persian *šabak* (New Persian *šabah*). In the field of medicine, jet was used against cataract of the eye and against nightmares.
As deposit sites, al-Bīrūnī (*Ǧamāhir*, p. 199) mentions Ṭabarān in Persia and the region to the east of the Dead Sea. Other sources mention India as the place of origin.

v. also *Steinbuch des Aristoteles*, pp. 107, 153–154 (reprint op, cit., pp. 115, 161–162); Tamīmī, *Muršid*, pp. 79–80, 170–171; Tīfāšī, *Azhār al-afkār*, p. 48 (reprint op, cit., p. 13); Qazwīnī, *ʿAǧāʾib al-maḫlūqāt,* p. 228; Ibn al-Baiṭār, *Ǧāmiʿ*, vol. 3, p. 4 (French transl., Leclerc, vol. 2, p. 237; German transl. Sontheimer, vol. 2, p. 4).

(3) Yellow-Red.
Diameter: 65 mm, 225 g.
(Inventory No. K 3.52c)

(2) Red-Violet.
Diameter: 100 mm, 850 g.
(Inventory No. K 3.52b)

(1) Green.
130 x 100 mm, 500 g.
(Inventory No. K 3.52a)

(4) Reddish.
Diameter: 50 mm, 45 g.
(Inventory No. K 3.52d)

(5) White.
75 x 45 mm, 130 g.
(Inventory No. K 3.52e)

ṭīn

Aluminium Oxide

Apart from the use of aluminium oxide for the manufacture of chemical ovens and the *ṭīn al-ḥukamāʾ*[1] (translated by Julius Ruska as “artificial clay”,[2] see above, p. 134) used in laboratories, Arabic physicians know several kinds of clay the knowledge of which they derived from Dioscorides and Galen. Ibn al-Baiṭār (*Ǧāmiʿ*, vol. 3, pp. 106-112) mentions among others:

1.– *Ṭīn maḫtūm*, “sealed” clay, terra sigillata (σφραγίς), handed down from Galen.
2.– *Ṭīn Miṣr*, Egyptian clay (thus Galen; Dioscorides calls it ἐρετριὰς γῆ).
3.– *Ṭīn Sāmūš*, clay from the island of Samos (σαμία γῆ), described by Dioscorides and by Galen.
4.– *Ṭīn Ǧazīrat al-Maṣṭikī*, clay from the island of Chios (χία γῆ), described by Dioscorides and by Galen.
5.– *Ṭīn Qīmūliyā*, clay from the Cyclades island Kimolos (κιμωλία γῆ), described by Dioscorides and by Galen, possibly identical with the aluminium oxide that the inhabitants of Basra called ṭīn ḥurr (Ibn al-Baiṭār, *Ǧāmiʿ*, vol. 3, p. 111).
6.– *Ṭīn karmī*, “grape-vine clay” (ἀμπελιτὶς γῆ), according to Dioscorides a black aluminium oxide from Seleucia in Syria.
7.– *Ṭīn armanī*, Armenian clay (ἀρμενία γῆ), described by Galen.
8.– *Ṭīn nīsābūrī*, clay from Nīšāpūr in north-east Persia.

French translation of the relevant descriptions in: Leclerc, vol. 2, pp. 421-427, German translation, v. Sontheimer, vol. 2, pp. 166-176.
v. also Dioscorides, book 5, chapter 172 ff., v. J. Berendes, p. 554 ff; Claudii Galeni opera omnia, ed. C. G. Kühn, vol. 12,

[1] Rāzī, *Asrār wa-sirr al-asrār*, p. 10.
[2] *al-Rāzī’s Buch Geheimnis der Geheimnisse*, op. cit., p. 96.

zabad al-baḥr and *sūraǧ*
Sepiolite (Meerschaum)

(1, on the right) smooth.
Dimensions: 35 x 25 mm, 5 g.
(Inventory No. K 3.46a)

(2, on the left) rough
Dimensions: 70 x 40 mm, 32 g.
(Inventory No. K 3.46b)

Arab scholars knew from their Greek predecessors Dioscorides and Galen two kinds of meerschaum under the names halkyonion and adarkes. Even though they generally differentiate between them, they call both of them *zabad al-baḥr* ("meerschaum"). In the writings of Ibn al-Baiṭār (*Ǧāmiʿ*, vol. 3, p. 43) the latter seems to occur as *sūraǧ*. It corresponds to sepiolite, which is a component of meerschaum. According to Dioscorides (book 5, chapter 136), adarkes is suitable "for the removal of leprosy, eczema, white spots, liver spots and such … it also helps with sciatica."[1]

Tamīmī, *Muršid*, pp. 105–108, 187–189; Muwaffaqaddīn al-Harawī, *Abniya*, p. 176 (transl. Achundow, p. 215; reprint p. 87); Ibn al-Baiṭār, *Ǧāmiʿ*, vol. 2, pp. 154–155 (French transl., Leclerc, vol. 2, pp. 196–197; German transl. Sontheimer, vol. 1, pp. 518–519); Qazwīnī, *ʿAǧāʾib al-maḫlūqāt*, p. 226.

[1] v. J. Berendes, op. cit., p. 541.

durr, lu'lu'
Pearl

In the field of medicine, the pearl is added to medicaments in pulverised form. It is used for strengthening the membranes of the eyes and their muscles, for strengthening the heart and against melancholy. As deposit sites, Arabic sources generally speak of the Indian Ocean, specially Bahrain in the Persian Gulf, Sri Lanka, the Red Sea (Dahlak Archipelago) and Zanǧibār (Zanzibar).

Diameter: 7.5 mm, 2.5 ct.
(Inventory No. K 3.39)

Steinbuch des Aristoteles, pp. 96–98, 130–133 (reprint op. cit. pp. 104–106, 138–143); Tamīmī, *Muršid*, pp. 35–40, 138–143; Bīrūnī, *Ǧamāhir,* pp. 104–137; Ibn al-Ǧazzār, *Iʿtimād*, facsimile ed., p. 31; Qazwīnī, *ʿAǧāʾib al-maḫlūqāt,* pp. 223–224; v. also E. Wiedemann, *Zur Mineralogie im Islam*, pp. 219–223, 231–232, 237–238, 254–255 (reprint op. cit., pp. 191–195, 203–204, 209–210, 226–227); J. Ruska, *Perlen und Korallen in der naturwissenschaftlichen Literatur der Araber*, in: Naturwissenschaftliche Wochenschrift (Jena) 20/1905/612–614 (reprint in: Natural Sciences in Islam, vol. 28, Frankfurt 2001, pp. 252–254); J.-J. Clément-Mullet, op. cit., pp. 16–30 (reprint op. cit., pp. 190–204).

mūmiyāʾ
Mineral Wax, Ozocerite

75 x 55 mm, 215 g.
(Inventory No. K 3.16)

"A hard, black and shining mineral liquid which oozes out of rock caves" (Dietrich). It occurs in Yemen, in southern Persia and in India. In medical applications, *mūmiyāʾ* is used for fractures, sprains, bruises, haematoma and for the treatment of wounds; it is also used as an antidote.

Ibn al-Ǧazzār, *Iʿtimād*, facsimile ed, pp. 112–113; Bīrūnī, *Ǧamāhir,* pp. 204–207; Ibn al-Baiṭār, *Ǧāmiʿ*, vol. 4, pp. 169–170 (French transl., Leclerc, vol. 3, pp. 346–349; German transl. Sontheimer, vol. 2, pp. 537-538); A. Dietrich, *Dioscorides triumphans*, pp. 20–21 (arabe), 120–121 (German).

(1) Red.
Diameter: 27 mm, 15 g.
(Inventory No. K 3.26a)

(2) White-blue.
Diameter: 25 mm, 13 g.
(Inventory No. K 3.26b)

(3) White.
Diameter: 110 mm, 0.7 kg.
(Inventory No. K 3.26c)

marǧān and *bussaḏ*
Corals

Marǧān and *bussaḏ* are quite frequently used as synonyms. In North Africa "coral" is called *qarn* ("horn"). It was known in red, white, black and blue colours.
Pulverised coral was used as a remedy for eye diseases, against stomach pain and pain in the spleen. As deposit sites, Arabic sources mention, inter alia, the coasts of the Mediterranean, the Red Sea and Sicily.

Steinbuch des Aristoteles, pp. 120, 176 (reprint op. cit. pp. 128, 184); Tamīmī, *Muršid,* pp. 71–76, 164–167; Bīrūnī, *Ǧamāhir,* pp. 189–193; Ibn al-Baiṭār, *Ǧāmiʿ*, vol. 1, pp. 93–94 (French Transl., Leclerc, vol. 1, pp. 223-225; German transl. Sontheimer, vol. 1, pp. 137–139); Qazwīnī, *ʿAǧāʾib al-maḫlūqāt*, p. 238; for turther literature, v. A. Dietrich in: EI, new ed., vol. 6, pp. 556–557.

kahrubāʾ, kahramān

Amber

(1) Light.
Diameter: ca. 47 mm. 19 g.
(Inventory No. K 3.09a)

(2) Dark.
Diameter: ca. 47 mm, 34 g.
(Inventory No. K 3.09b)

Amber, in Persian "straw-robber" (*kāh-rubā*) in the sense of attracting straw, is not considered a stone by Arab-Islamic scholars, but mostly as a resin or a plant product. Arab physicians adopted amber from their Greek predecessors[1] as a styptic, a heart-strengthening medicament and as a relief for pain in the eyes. Al-Bīrūnī[2] says that he included amber in his book of gems only because it was known and popular among the eastern Turks. Obviously the knowledge of amber's property of attracting straw after being rubbed, which al-Bīrūnī mentions as something that is well known, reached the Muslims from the Chinese via the eastern Turks.[3] The coasts of the Caspian Sea, the Mediterranean and the eastern coasts of the northern and southern Atlantic Ocean are mentioned as deposit sites.

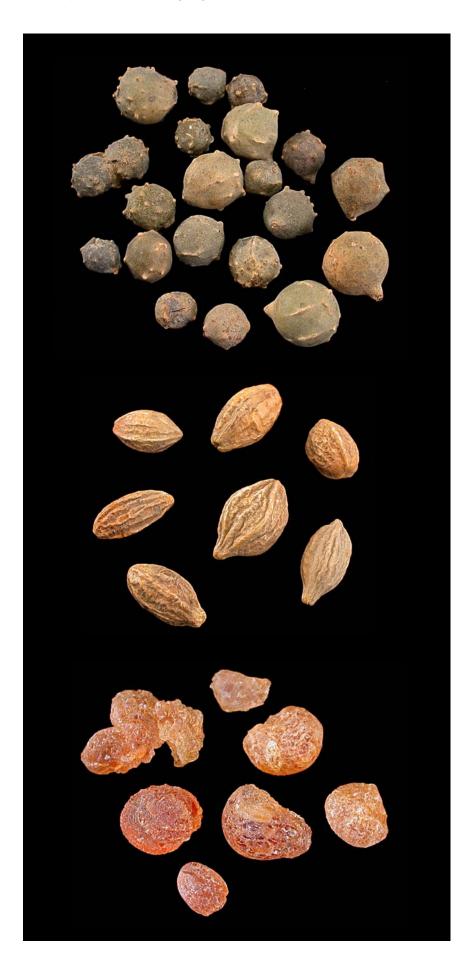
ʿAlī b. Rabban aṭ-Ṭabarī, *Firdaus al-ḥikma*, Berlin 1928, p. 405 (see Werner Schmucker, *Die pflanzliche und mineralische Materia Medica im Firdaus al-Ḥikma des ʿAlī ibn Sahl Rabban aṭ-Ṭabarī*, Bonn 1969, pp. 414–415); Ibn al-Ǧazzār, *Iʿtimād*, facsimile ed, pp. 18; Qazwīnī, *ʿAǧāʾib al-maḫlūqāt* pp. 234; Ibn al-Baiṭār, *Ǧāmiʿ*, vol. 4, pp. 88–89 (French transl., Leclerc, vol. 3, pp. 209–211; German transl. Sontheimer, vol. 2, pp. 405–406); Georg Jacob, *Der Bernstein bei den Arabern des Mittelalters*, Berlin 1886 (reprint in: Natural Sciences in Islam, vol. 28, Frankfurt 2001, pp. 115–126); idem, *Neue Studien, den Bernstein im Orient betreffend*, in: Zeitschrift der Deutschen Morgenländischen Gesellschaft (Leipzig) 43/1889/353–387 (reprint in: Natural Sciences in Islam, vol. 28, pp. 127–161); Oskar Schneider-Dresden, *Nochmals zur Bernsteinfrage*, in: Zeitschrift der Deutschen Morgenländischen Gesellschaft (Leipzig) 45/1891/239–244 (reprint in: Natural Sciences in Islam, vol. 28, pp. 163–168); G. Jacob, *Kannten die Araber wirklich sicilischen Bernstein?*, in: Zeitschrift der Deutschen Morgenländischen Gesellschaft (Leipzig) 45/1891/691–693 (reprint in: Natural Sciences in Islam, vol. 28, pp. 169–171); Eilhard Wiedemann, *Zur Mineralogie bei den Muslimen*, in: Archiv für die Geschichte der Naturwissenschaften und der Technik (Leipzig) 1/1908–09/208–211, esp. p. 211 (reprint in: Natural Sciences in Islam,

[1] v. Ibn al-Baiṭār, *Ǧāmiʿ*, vol. 4, pp. 88–89.
[2] *Ǧamāhir,* p. 210.
[3] F.M. Feldhaus says in his *Die Technik. Ein Lexikon der Vorzeit, der geschichtlichen Zeit und der Naturvölker* (Wiesbaden 1914, repr. Munich 1970), column 78: "Electricity of amber was already known to the Chinese around 315 AD. In Europe only Gilbert recognised this power of nature (Gilbert, *De magnete*, London 1600)."

Gallnuts or Galls

Excrescence of plant tissue induced by gall wasps; used in the extraction of tannic acid (Tannin)

20 pieces.
Total weight 50 g.
(Inventory No. K 3.60)

Myrobalans

Fruit of *Terminalia chebula*, rich in tanning agent.

7 pieces.
Total weight 27 g.
(Inventory No. K 3.62)

Gum arabica

Dried juice of African Acacias, high-quality water-soluble bending agent.

7 ‹tears›.
Total weight 67 g.
(Inventory No. K 3.61)

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Science and Technology
in Islam

V

SCIENCE AND TECHNOLOGY IN ISLAM

VOLUME V

Catalogue of the collection
of instruments of the Institute for the History
of Arabic and Islamic sciences

by

Fuat Sezgin

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Translated by

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and

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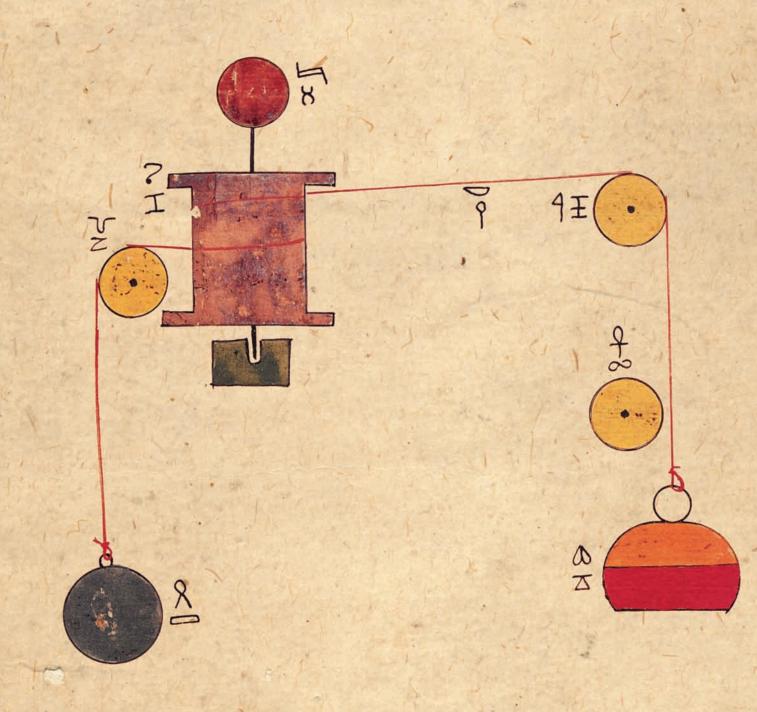
10. PHYSICS AND TECHNOLOGY
11. ARCHITECTURE • 12. MILITARY TECHNOLOGY
13. ANCIENT ARTEFACTS

2010
Institut für Geschichte der Arabisch–Islamischen Wissenschaften
an der Johann Wolfgang Goethe-Universität
Frankfurt am Main

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Chapter 10

Physics & Technology

Weighing Balances

"All the weighing balances occuring in Antiquity and the Middle Ages are lever balances and consist of a beam (*ʿamūd*, also *qaṣaba*) that can be turned around a horizontal axis (*miḥwar*), that is to say, a lever whose centre of gravity lies below the axis. The object to be weighed (the load) is suspended from one arm of the beam, and the weights which weigh it are suspended from the other, usually in pans. Here the arms can be of equal length or not; thus the balances are of equal arms or of unequal arms."[1]

"While dealing with the theory of balances we have to consider first the definition of the heavy and light bodies, the determination of the centre of gravity, that of the stable, the unstable and the indifferent equilibrium caused by the opposite positions of the centre of gravity and the fulcrum, the investigation of the question of any likely impact when the loads are attached directly to the lever arm itself or to staves connected to this lever, staves which are perpendicular to the beam and are inclined towards it."[2]

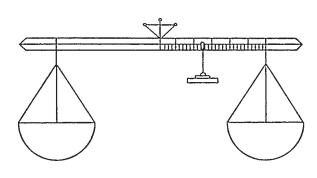
There can be no doubt that the Arabs possessed a functioning form of balances before the advent of Islam and in Early Islam. They also make no secret of the fact that they borrowed the theoretical discussion of balances from the Greeks. In the middle of the 3rd/9th century, the author and natural philosopher al-Ǧāḥiẓ mentions the steelyard or the Roman balance (*qarasṭūn*) among the objects inherited from the Greeks.[3]

Al-Qarasṭūn (χαριστίων) "is a two-armed, unequally armed lever whose point of gravity lies under the fulcrum. The object to be weighed, the load G_1, is situated on the shorter arm at a distance of l_1 from the fulcrum; the weight G_2 that serves for the weighing, viz. the sliding weight (*rummāna*), can be moved on the longer arm. When equilibrium is achieved at a distance l_2, then $G_1 \bullet l_1 = G_2 \bullet l_2$ or $G_1 : G_2 = l_2 : l_1$, i.e. at equilibrium the weights G_1 and G_2 are inversely proportionate to the distances $l_1 : l_2$."[4]

The law of the lever, which was apparently first formulated by Archimedes, appears to have been recognized in its full significance in the Arab-Islamic world from the 3rd/9th century, perhaps even from the 2nd/8th century. Although the Arabic works written on this subject in the 3rd/9th century are all lost but for a few, among the survivals of the genre which have been made available to research so far there is one of their most important representatives. It is the *Kitāb al-Qarasṭūn*[5] by Ṯābit b. Qurra (d. 288/901), one of the greatest scholars of the Arab-Islamic world.[6] Like many of his writings, this book by Ṯābit b. Qurra also had a considerable impact in its Latin translation in the West, even though the most important achievement of the author is lost on the reader because of the inaccuracy of the translation. It is his line of argumentation which, in its conclusion, leads to the concept of the infinitely small, a method of studying the infinitesimal processes which was unknown to the Ancients.[7]

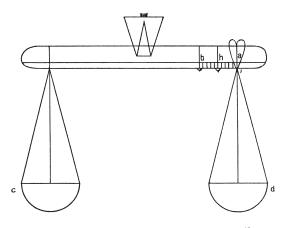
The advances made in the theoretical discussion and in the practical achievements in dealing with the weighing balance in the Arab-Islamic region until the beginning of the 6th/12th century can be traced, thanks to the excellent extant work on the *mīzān al-ḥikma*, the "Balance of Wisdom" by ʿAbdarraḥmān al-Ḫāzinī (written 515/1121).[8]

[1] Eilhard Wiedemann, *ḳarasṭūn* entry in: *Enzyklopädie des Islām*, vol. 2, Leiden and Leipzig 1927, col. 810 b.

[2] ibid., col. 811 a.

[3] *Kitāb al-Ḥayawān*, ed. ʿAbdassalām Hārūn, vol. 1, Cairo 1938, p. 81; E. Wiedemann, op. cit., col. 811 b.

[4] E. Wiedemann, op. cit., col. 811 a.

[5] Ferdinand Buchner, *Die Schrift über den Qarastûn von Thabit b. Qurra*, in: Sitzungsberichte der Physikalisch-medizinischen Sozietät (Erlangen) 52–53/1920–21/141–188 (reprint in: Islamic Mathematics and Astronomy, vol. 21, Frankfurt 1997, p. 111–158); Khalil Jaouiche, *Le livre du qarasṭūn de Ṯābit ibn Qurra. Étude sur l'origine de la notion de travail et du calcul du moment statique d'une barre homogène*, Leiden 1976.

[6] F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 3, pp. 260–263; vol. 5, pp. 264–272; vol. 6, pp. 163-170.

[7] F. Buchner, op. cit., p. 162–163 (repr., op. cit., pp. 132–133).

[8] Nicolas Khanikoff, *Analysis and extracts of* Kitāb Mīzān al-ḥikma [en arabe dans l'original] *"Book of the Balance of*

mīzān Aršimīdis after al-Ḫāzinī (Th. Ibel, *Die Wage*, p. 52).

The ‹physical balance› described by ar-Rāzī[12] (Th. Ibel, *Die Wage*, p. 154).

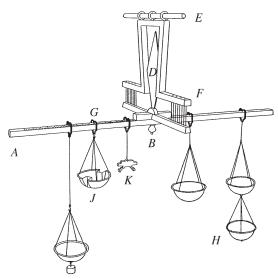
[4] The work also gives a rather good overview of the preceding literature on the subject. At first al-Ḫāzinī describes a balance designated as Archimedean (*mīzān Aršimīdis*).[9] It is "a common equal-armed balance with two equal pans, the left pan for gold and the right one for silver. On the right arm a weight slides in order to create the equilibrium."[10] The decisive factor for a continuous development both in the technical and in the literary field was the testing of gold, silver and other metals and their alloys. The balances serving this purpose with sliding pans and sliding weights, which were undoubtedly based on the Archimedean tradition, led to the concept of "physical balance" (*mīzān ṭabīʿī*). The physician and natural philosopher Abū Bakr Muḥammad b. Zakarīyā' ar-Rāzī (d. 313/925)[11] was probably the first person in the Islamic world to make use of these balances.

Wisdom", an Arabic work on the water-balance, written by al-Khâzinî, in the twelfth century, in: Journal of the American Oriental Society (New Haven) 6/1860/1–128 (repr. in: Natural Sciences in Islam, vol. 47, Frankfurt 2001, pp. 1–128); Thomas Ibel, *Die Wage im Altertum und Mittelalter*, Erlangen 1908, pp. 73–162 (repr. in: Natural Sciences in Islam, vol. 45, Frankfurt 2001, pp. 77–166); C. Brockelmann, *Geschichte der arabischen Litteratur*, 1st suppl. vol, p. 902. The text was published in Hyderabad 1940, after a manuscript from a mosque in Mumbai (repr in: Natural Sciences in Islam,vol. 47, Frankfurt, 2001 pp. 219–510).

[9] *Mīzān al-ḥikma*, ed. Hyderabad, pp. 78–79 (repr., op. cit., pp. 392–395).

[10] Th. Ibel, *Die Wage*, p. 51 (repr., op. cit., p. 55).

[11] v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 3, pp. 274–294; vol. 4, pp. 275–282, 345; vol. 5, pp. 282, vol. 6, pp. 187–188, vol. 7, pp. 160, 271–272.

[12] Al-Ḫāzinī (Arabic text, Hyderabad, p. 83, repr., p. 386) quotes ar-Rāzī's description in the following way: "For the determination of each body and its excess of [weight] over another body and for determining this characteristic through the physical balance, we take a balance that has been tested as carefully as possible; the expression "careful testing of the balance" means that we take two weighing pans which hold the same volume of water and that we make them equal in weight, to be precise, in such a manner that we file off something from the outside, and not by cutting off something from it because then we would reduce its capacity for holding. When both pans are equal, we take a uniform, carefully tested beam; the entire beam has the shape of the *qabbān* (steelyard) which is made in a convex shape. Then we suspend one of the pans from it. We assign a place to the second pan at the end of the beam, this one being suspended by means of the ring through the end of the thread on this pan. The ring has a pointed end." (Translated from Th. Ibel, *Die Wage*, op. cit., p. 153; repr., op. cit., p. 157). "On the scale pan at the left it says ‹pan for silver, it is fixed›, on the right pan ‹pan for gold, it is movable› … The substance to be weighed is placed in the fixed pan, in the movable pan a weight that corresponds to it. The fixed pan is now submerged in water and the sliding pan is moved so long, approximately up to h, until the balance is again at rest. Once we have thus established the point a or b where the pan rests if pure silver or pure gold is used, then the amount of alloy can be easily determined. If for the experiment with the alloy the pan is at *h*, then the proportion of the amount of gold to that of silver is like *ah* : *hb* " (Th. Ibel, *Die Wage*, op. cit., p. 154; repr., op. cit., p. 158). Al-Ḫāzinī (Arabic text, Hyderabad, between pp. 86 and 87, repr., p. 380) gives a second illustration of ar-Rāzī's balance. It apparently shows the alternative use of iron weights (cf. Th. Ibel, Die Wage, op. cit., p. 154; repr., op. cit., p. 158).

The ‹Balance of Wisdom›

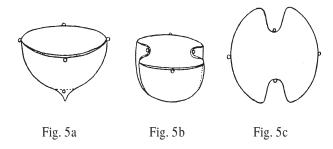
(*mīzān al-ḥikma*)

The ‹balance of Wisdom› (*mīzān al-ḥikma*) of al-Ḫāzinī, after the *Encyclopédie de l'Islam*, vol. 3, column 611 (art. *mīzān*).

Our model:
Total height: 135 cm.
Brass, partly gilded, with ornamentation.
Balance beam (Momentenarm) with engraved millimetre scale and numbers, length: 98 cm.
5 gilded scale pans besides the weight.
(Inventory No. E 1.01))

The highest stage in the development of balances proves to be the actual "Balance of Wisdom" (*mīzān al-ḥikma*) which was developed around 500/1115 by Abū Ḥātim al-Muẓaffar b. Ismāʾīl al-Isfizārī[13] and perfected by his contemporary ʿAbdarraḥmān al-Ḫāzinī.[14]

"Al-Ḫāzinī gives the beam *A* of the balance (see fig. above) a thickness of 6 cm and a length of 2 m. In the centre it is strengthened by an additional piece *C*, obviously intended to avoid any bending at this point. *A* cross-piece *B* (*ʿarīḍa*) is let in here. Corresponding to it is a similar cross-piece *F* on the lower part of the fork, in which the tongue *D* moves, itself about 50 cm long."

[13] v. al-Baihaqī, *Taʾrīḫ ḥukamāʾ al-islām*, Damascus 1946, pp. 125–126; C. Brockelmann, *Geschichte der arabischen Litteratur*, 1rst suppl.-vol., p. 856. His book on balances with the title *Iršād ḏawi l-ʿirfān ilā ṣināʿat al-qabbān* is preserved in an incomplete manuscript, Cairo, Dār al-kutub al-miṣrīya, riyāḍ. 1021 (9 ff.).

[14] C. Brockelmann, *Geschichte der arabischen Litteratur*, suppl., vol. 1, p. 902.

"The upper cross-piece *E* is hung by rings to a rod which is fastened in some way. Pegs or small holes are placed at exactly opposite places of the cross-pieces *B* and *F*, to which threads are tied or drawn through. The friction at an axis is thus avoided, which, in view of the great weight of the beam, is quite considerable. The knob visible below the beam under its centre is used to secure the tongue to the beam or to take it out in order to adjust it evenly. The tongue has for this purpose a peg at the foot which goes through a hole in the beam. Al-Ḫāzinī also observes that shorter beams could also be taken, but then all the other dimensions must be proportionately smaller. The beam is divided not on one side only, as in the illustration, but on both. The scales are hung on very delicate rings of steel (*ġurāb*, "ravens"), the points of which fit into little niches on the upper surface of the beam."

"Five scales are used in ascertaining specific gravities, i.e. in investigating alloys and examining precious stones. Of these, the scale *H* (fig. 5a) is called the cone-shaped or *al-ḥākim*, ‹the judge›, as it is used to distinguish false from true. It goes into the water, and in order to meet less resistance in sinking, is cone-shaped and pointed below. The scale *J* is called the winged one (*muǧannaḥ*) (fig. 5b and 5c, side and top view)."

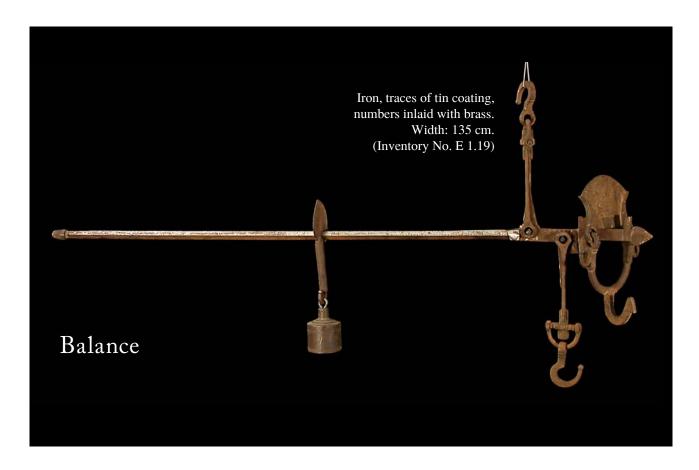
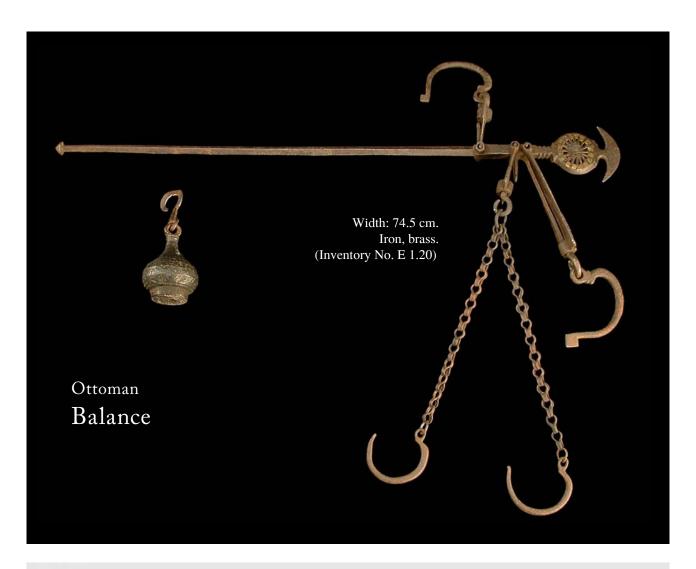
"It had indented sides so that it can be brought very close to the adjoining scales. It is also called the moveable piece (*munaqqal*). There is also a moveable running weight *K* (*rummāna saiyāra*) which serves, if necessary, to adjust the weight of the lighter beam; it is therefore also called the *rummāna* of the adjustment (*taʿdil*). The other scales are used to hold weights. Al-Ḫāzinī attained an extraordinary degree of accuracy with this balance. This was the result of the length of the beam, the peculiar method of suspension, the fact that the centre of gravity and axis of oscillation were very close to each other and of the obviously very accurate construction of the whole. Al-Ḫāzinī himself says that when the instrument was weighing 1,000 miṯqāls, it could show a difference of 1 *ḥabba* = 1/68 *miṯqāl*, i.e. about 75 cg. in 4.5 kg. We thus have accuracy to 1/60000."

"Al-Ḫāzinī used his scales for the most varied purposes. Firstly, for ordinary weighing, then for all purposes connected with the taking of specific gravities, distinguishing of genuine (*ṣamīm*) and false metals, examining the composition of alloys, changing of dirhams to dīnārs and countless other business transactions. In all these processes, the scales are moved about until equilibrium is obtained and the desired magnitudes in many cases can at once be read on divisions on the beam."[15]

Fig. 5a Fig. 5b Fig. 5c

Scales after al-Ḫāzinī, in: *Enzyklopädie des Islam*, vol. 3, col. 611 (art. *mīzān*).

[15] Eilhard Wiedemann, article *al-mīzān* in: Encylopaedia of Islām, new edition, Leiden and New York 1993, vol. 7, pp. 197 a-198 a; al-Ḫāzinī, *Mīzān al-ḥikma*, ed. Hyderabad 1359/1940, pp. 92 ff., repr., op. cit., from p. 367 backwards; abridged English translation: C. N. Khanikoff, *Analysis and Extracts of ..., Book of the Balance of Wisdom ...* in: Journal of the American Oriental Society (New Haven) 6/1860/1-128; Th. Ibel, *Die Wage*, op. cit., pp. 112 ff.; repr., op. cit., pp. 116 ff.

Iron, traces of tin coating, numbers inlaid with brass. Width: 135 cm. (Inventory No. E 1.19)

Balance

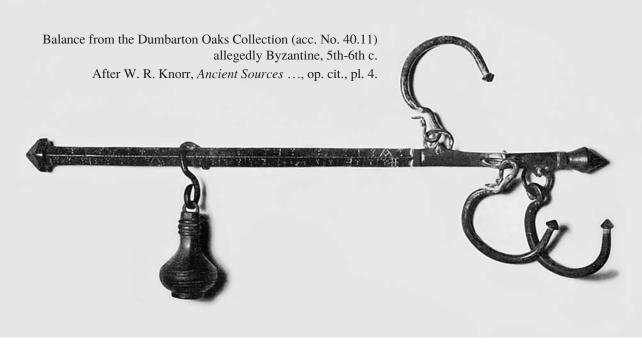
One specimen is said to have come down from the early stages of development of the balance in the early centuries of Arab-Islamic culture. The specimen preserved in the Science Museum in London is dated 4th/10th century (see fig. below). The length of the beam is about 2.5 m.[16]

Our balance, acquired in Egypt, shows a striking similarity to the London specimen. Its age is not known, but the provenance, workmanship and state of preservation allow for hardly more than 150 years. The arm is divided into 34 units of about 2.9 cm (according to the labels: 60-230); these units are subdivided into 5 points each.

Fig. from W.R. Knorr, op. cit., pl. 11.

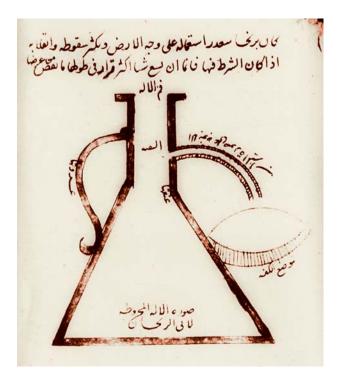
[16] v. Wilbur Richard Knorr, *Ancient sources of the medieval tradition of mechanics. Greek, Arabic and Latin studies of the balance*, Florence 1982, plate 11 after p. 117.

Width: 74.5 cm.
Iron, brass.
(Inventory No. E 1.20)

Ottoman
Balance

Balance from the Dumbarton Oaks Collection (acc. No. 40.11)
allegedly Byzantine, 5th-6th c.
After W. R. Knorr, *Ancient Sources* …, op. cit., pl. 4.

Numerical determination of the specific gravity

Our model:
Glass vessel, height: 34 cm with measuring beaker.
Balance of brass on hardwood, height: 48 cm.
(Inventory No. D 1.23)

“The scholars of Antiquity undertook numerous and precise measurements; e.g. Archimedes, because otherwise he could not have solved the task assigned to him of determining the composition of Hieron’s wreath [the crown of King Hieron of Sicily]; likewise Menelaus. No figures have come down to us …”

“The numerical values achieved by the Muslim scholars mentioned by al Bîrûnî have not survived. Of Abu ’l-Faḍl [Ǧaʿfar b. ʿAlī ad-Dimašqī], we know at least the method employed. The first data, both for metals and for precious stones, which we know are from al Bîrûnî …”

“Al Bîrûnî experimented with the greatest care. He performed all the weighings and measurings at the same place and in the same season, thus avoiding quite a few errors. He selected the metals to be compared in as pure a form as possible. Thus he purified gold five times in fire until it became difficult to melt any further and solidified quickly. He pressed mercury through sheets of cloth for so long until it seemed quite pure to him. Before using the purified lead, he also removed the layer of oxide that was forming. He knew quite well that a little bit of silver was still admixed in it but he could not remove its last traces. He treated silver, copper, iron and tin with the same care. Because of their importance he also examined two alloys: bronze (*ṣufr*), composed of copper and tin, and brass (*šabah*)”

“After these preliminary procedures, al Bîrûnî set himself the task of ascertaining the weights of equal volume. For this he at first employed the methods adopted by his predecessors, but he gives detailed information only about the method of Aḥmad ibn al Faḍl [al-Buḫārī],[1] who used a casting mould which was commonly employed in metal casting. The casting mould of al Bîrûnî held 40 *miṯqāls*[2] of iron. Probably the choice of this volume came about by chance. He gave it the shape of a lentil. He filled the empty space of the model with different molten metals and then weighed them. He repeated this several times to convince himself of the accuracy of the results. Every time he got different values because the form did not remain completely stable. Therefore he gave up this method ‹since it gave only surmises, not certainties.› In order to arrive at a more stable form, he cut a hollow cavity in the shape of a hemisphere into a steel anvil and filled it up with molten metals, hammered the mass and filed off the excess. He tested it with a ruler until the surface of the metal coincided with the level of the anvil. But here too he arrived at variable results when he repeated the procedure. Then al Bîrûnî tried to achieve results with a completely different procedure. Into two steel plates A and B round holes of the thickness of a finger were bored. Then A and B were fastened onto two iron cylinders in such a way that the holes were exactly opposite to one another. The holes were used to draw wires of a certain thickness through them, with wires being given the same length each time. He thus hoped to achieve volumes of consistently the same dimensions. But repeated experiments showed him that the weights of the wires of the same metal did not quite agree with one another; therefore he abandoned this method as well.”[3]

[1] Probably lived in the 4th/10th cent., quoted by al-Ḫāzinī, *Mīzān al-ḥikma*, ed. Hyderabad, p. 56 (repr., op. cit., p. 437).
[2] 1 *miṯqāl* ≈ 4.5 g.
[3] Heinrich Bauerreiß, *Zur Geschichte des spezifischen Gewichtes im Altertum und Mittelalter*, Erlangen 1914, pp. 28-29 (repr. in: Natural Sciences in Islam, vol. 45, Frankfurt 2001, pp. 224-225).

Then al-Bīrūnī turned to the possibility of ascertaining the specific gravity by means of the displacement of water when the material to be measured was submerged in a measuring beaker:

al-Bīrūnī’s pycnometer from MS Beirut 223..

“As the inventor himself mentioned, he only succeeded after several attempts in giving the final shape to the vessel (v. fig.).” “He gave it a conical shape; through the large base it had corresponding stability and could hold a great deal of material. On the top is attached a narrow neck of uniform width. […] The smallest objects had the shape of a millet seed. To the middle of the neck, a tube is soldered, which has the form of a quarter circle, and its end is situated above a bowl, which is meant for collecting the displaced water. Holes were bored into the tube from above to prevent the water from remaining in the tube. However, al Bîrûnî remarks that this objective was not always fully achieved.”[4] During his experiments, al-Bīrūnī always took into account the nature and the tem

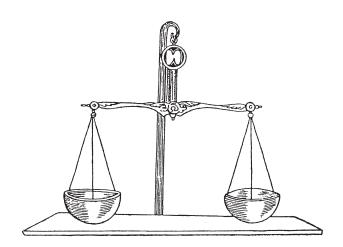
[4] H. Bauerreiß, op. cit., p. 41 (repr., op. cit., p. 237).

perature of the water [11] and he used to perform all his experiments "with the same kind of water and in the same season".[5]
The specific gravities of many metals and precious stones ascertained in the course of time by al-Bīrūnī and by other scholars of the Islamic world with minor variations agree completely or almost completely with the corresponding modern values.[6]
E. Wiedemann was convinced that these methods of experimentation of the Arab-Islamic world also reached Venice and from there the scholars of Italy, among them Galileo Galilei.[7] In his view[8] "in his *Bilancetta* Galilei used almost exactly the same methods" which were used widely in the Islamic world.
The instrument invented by al-Bīrūnī which functions according to the principle of displacement of the volume of water is basically nothing but the pycnometer,[9] well-known in our times. Its first known pictorial depiction in the West (see fig.) can be traced to Wilhelm Homberg (1699). Here, in the same way as in the case of al-Bīrūnī, "the liquid is filled until it reaches just up to the tip of the small capillary tube."[10]
The pycnometer attained its subsequent accuracy in the work of Johann Heinrich Geißler (1815 -1879).[11]

Early European pycnometer by Wilhelm Homberg (1699) after Gerland and Traumüller..

A balance similar to our model is printed here (see fig.) after the Lucknow edition of 1893 of the *Āʾīn-i Akbarī* by Abu l-Faḍl ʿAllāmī (c. 1010/1600), as reproduced by Th. Ibel.[12]

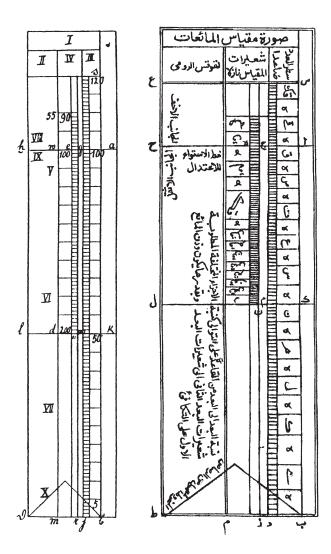
Balance of Abu l-Faḍl ʿAllāmī after Th. Ibel.

[5] H. Bauerreiß, op. cit., p. 55 (repr., op. cit., p. 251).
[6] v. E. Wiedemann, *Arabische specifische Gewichtsbestimmungen*, in: Annalen der Physik (Leipzig) 20/1883/539-541 (repr. in: *Gesammelte Schriften*, vol. 1, pp. 30-32); idem, *Über das Experiment im Altertum und Mittelalter*, in: Unterrichtsblätter für Mathematik (Frankfurt) 12/1906/73-79, 97-102, 121-129, esp. p. 125 (repr. in: *Gesammelte Schriften*, vol. 1, pp. 147-168, esp. p. 164).
[7] *Arabische specifische Gewichtsbestimmungen*, op. cit., p. 541 (repr., p. 32); *Über das Experiment im Altertum*, op. cit., p. 125 (repr., p. 164). On the treatment of the subject by Galileo in *La Bilancetta* v. H. Bauerreiß, *Zur Geschichte des specifischen Gewichtes*, op. cit., pp. 62-64 (repr., pp. 258-260); Galileo Galilei. *Schriften, Briefe, Dokumente*, ed. by Anna Mudry, vol. 1, Munich 1987, pp. 45-49.
[8] *Über das Experiment im Altertum*, op. cit., p. 125 (repr., p. 164).
[9] v. E. Wiedemann, *Die Naturwissenschaften bei den orientalischen Völkern*, in: Erlanger Aufsätze aus ernster Zeit, 1917, pp. 49-58, esp. p. 54 (repr. in: *Gesammelte Schriften*, vol. 2, pp. 853-862, esp. p. 858).
[10] E. Gerland, F. Traumüller, *Geschichte der physikalischen Experimentierkunst*, Leipzig 1899 (repr., Hildesheim 1965), p. 255.
[11] ibid.

[12] *Die Wage*, op. cit., p. 111 (repr., p. 115).

Areometer

Our model:
Brass, engraved.
Height: 304 mm.
Diameter: 44 mm.
Specific gravities of some liquids in Arabic characters.
Glass cylinder with a gilt brass lid.
Next to it on the right a modern areometer in a glass vessel.
A hardwood board with slots for the vessels.
(Inventory No. D 1.24)

Al-Ḫāzinī, frequently referred to above, mentions in the 7th chapter of the first treatise of his *Mīzān al-ḥikma*[1] the instrument which is called areometer in our times for the determination of the specific gravity of liquids (*miqyās al-māʾīyāt fi ṯ-ṯiqal wa-l-ḫiffa*). He mentions a certain Qūqus ar-Rūmī as the inventor of this instrument, who can probably be identified with Pappus; he was active at the turn of the 3rd to the 4th century in Alexandria. Such an instrument seems to have been known in Late Antiquity even before 415,[2] but the name of the inventor is mentioned only by al-Ḫāzinī.

Al-Ḫāzinī begins his description of the instrument with the physical principle on which it is based: "The ratio of the volumes of bodies of the same weight (and of the same substance) submerged in water behave [read: behaves] inversely to those [read: that of the] specific gravities.[3]"
"[13] If one accepts this principle, one can then construct an instrument which shows us the proportion of the weights of all liquids with the least trouble, provided the bodies have the same volume. It is also extremely useful in matters ben-

[1] ed. Hyderabad, pp. 28-33 (repr., op. cit., pp. 472 -481).
[2] E. Gerland, F. Traumüller, *Geschichte der physikalischen Experimentierkunst*, op. cit., p. 58; H. Bauerreiß, *Zur Geschichte des spezifischen Gewichtes*, op. cit., p. 96 (repr., op. cit., p. 292).

[3] The precise wording goes back to H. Bauerreiß (op. cit., p. 98; repr., p. 294) who proposes it as a correction to the version handed down in the surviving text which runs thus: "The ratio of the volume of any heavy body to the volume of another heavy body when they are equally heavy in air corresponds to the inverse ratio of the weight to the weight in water" (al-Ḫāzinī, *Mīzān al-ḥikma*, ed. Hyderabad, p. 28; repr., op. cit., p. 481).

eficial to the health of the human body; all of this without the need to use weights and a balance."[4]
"The instrument consists of a hollow cylinder which is about half a cubit long (ca. 28 cm) and which has a diameter of 2 fingers' breadth (ca. 4 cm) or less. The material is copper (nuḥās, sometimes also used for copper alloys[5]). The cylinder is turned on the lathe and is as light as possible. Its ends are closed by two bases which resemble the light frame drums (*duff*) and are fitted on the lathe as carefully as possible. On the lower surface a cone of lead (*raṣāṣ*) is attached in the inside … When the instrument is placed upon a liquid in a vessel, it stands exactly vertically on that surface and does not tilt to any side."[6]
By a diagram al-Ḫāzinī illustrates the precise description of how he proceeded in drawing the lines on the instrument.[7] We reproduce the description here from the edition of the Arabic text and from the version of Bauerreiß (see figs. on the right):
On the surface of the instrument it is necessary to draw "first of all a line *s a b* along the entire cylinder. About $\frac{1}{6}$th part or less of the cylinder is above the surface of the water (near *a*). To a b the parallel lines *g j, e r, n m, ḫ ϑ*, are drawn, running from the top to the bottom. *a b* is halved at *k; n r, d m* and l *ϑ* are made equal to *a k*. Through *k*, m_1, *n*, *l* is drawn a circular line with the help of a curved ruler placed against the cylinder, likewise a circle is drawn through *a g e ḫ*. This line is called the equator of equilibrium. The part lying above the equator represents specific gravities lower than that of water, the part below represents those higher than that of water."
"Then the line a b is divided into 10 parts, which are labelled with letters according to their numerical value, and through the dividing points are drawn arcs terminating at *g j* and *a b*. The area between each two dividing lines on *g j* is again subdivided into 10 parts so that *g j* is divided into 100 parts. Now through the 100 parts of *g j* are drawn small equidistant arcs, which are parallel to the circles at the bases. In the area between the lines *a b* and *g j* are written the numbers in letters of the alphabet, beginning with *b* and proceeding towards *a*; [14] this is called the line (the scale) of the regularly proceeding numbers (*saṭr al-ʿadad al-mustawī*)".
"In order to find from these data a norm for the numbers proportionate to the (specific) gravities which are then inscribed upon the instrument, the procedure is the following. It is imagined that a vessel is present, such as a *dauraq* (water pitcher) [in our model a glass cylinder], which holds 100 *miṯqāls* etc. The height of the vessel is assumed to be 100, corresponding to the water contained therein. In order to arrive at the above mentioned

Labels (scales) of the areometer according to al-Ḫāzinī (from the Arabic edition and German translation by Bauerreiß).

[4] al-Ḫāzinī, op. cit., p. 28 (repr., p. 481); H. Bauerreiß, op. cit., p. 98 (repr., p. 294). In the following, the translation is slightly modified.
[5] v. J. W. Allan, *Persian Metal Technology 700-1300 AD*, Oxford 1979, p. 52.
[6] al-Ḫāzinī, op. cit., p. 29 (repr., p. 480); H. Bauerreiß, op. cit., p. 100 (repr., p. 296).
[7] al-Ḫāzinī, op. cit., between p. 30 and p. 31 (repr., p. 477); H. Bauerreiß, op. cit., p. 100 (repr., p. 296).

proportionate numbers, one multiplies 100 with 100, thus arriving at 10 000; this number is divided by the numbers inscribed earlier on the areometer up to where it is submerged in the liquid. The results of the division are put together in a table, in fact, along with the values from which they are computed, and they are then inscribed on the areometer itself between *n m* and *e r*. The graduations themselves are incorporated with a curved ruler. The numbers continue in the direction from *a* to *b*. Those above the line of equilibrium correspond to liquids lighter than water and those below to liquids heavier than water. The basis of the calculation is subsequently proved. Abu r-Raiḥān [al-Bīrūnī] pointed to it in his treatise."[1]

"The table which gives the specific gravities corresponding to the volumes of 110 to 50 is calculated very carefully according to the formula $s = 10\,000 : a$, where s is the specific gravity, a the volume which is read off."[2]

[1] al-Ḫāzinī, op. cit., pp. 29-30 (repr., pp. 479-480); translated by H. Bauerreiß, op. cit., pp. 101-102 (repr., pp. 297-298).
[2] H. Bauerreiß, op. cit., pp. 102-103 (repr., pp. 298-299).

Wood, iron; ∅ on top: 5-30 cm
(Inventory No. J 2.27-32.)

Six
measures of capacity
Egypt, 13th/19th – early 20th cent.?

The vessels, of different sizes and resembling bushels, are put together with thin strips of wood like very thin-walled drums or tubs, though completely encased outside with iron. From this we may infer that they were meant for measuring liquids. Their age can hardly be estimated; a fairly new branding stamp (see right) of the Egyptian municipal authority shows that they were still in use at any rate in the 14th/20th c. The construction possibly represents an older tradition.

Screw pump

Our model: Wood and plastic.
Size: 101 × 62 cm with table and transparent cover.
Electric motor for demonstration.
(Inventory No. E 1.15)

The screw is set in motion by a water wheel which is driven by the river current. The transmission takes place via two gearwheels which allow an inclination of about 30 degrees for the screw. The screw itself rests in a wooden cylinder and can be rotated. With its rotation water from the river is raised to a higher level, from where it can be directed to the fields.
A simple screw pump without a water wheel and gearwheels is described by the Roman scholar Vitruvius (Marcus Vitruvius Pollio, d. ca. 25 B.C.)[1] in his *De architectura*.[2] In more recent times (1886) Hugo Blümner[3] drew attention to the instrument: “Moreover, for draining the water from pits the so-called Egyptian screw (κοχλίας, cochlea) was used, an invention which Archimedes is supposed to have made during an Egyptian journey but which was most probably a piece of equipment that was known for a long time in Egypt which Archimedes merely brought back to Europe.”
In 1914 F. M. Feldhaus[4] expressed reservations: “Screw-pump, also called Archimedean snail or Egyptian screw. Archimedes got to know the screw pump during a journey to Egypt around 250 B.C. (Strabo, book 17, 807; Diodor. Sicul., book I, 34 and 5, 37; Vitruvius, book 10, 11). Accordingly the machine should be Egyptian. But it is not known from any Egyptian painting; the screw is not known in Egypt either.” As regards the first of the two reservations recorded here, we may say that it is nothing but a misuse of the argumentum ex silentio. As far as the second is concerned, it has not yet been established that the screw was not known to the Egyptians.

[1] v. G. Sarton, *Introduction to the History of Science*, vol. 1, pp. 223-225.
[2] Book 10, chapter 11, v. *Vitruv: Baukunst*, transl. August Rode, 2 vols., Leipzig 1796 (repr. Zurich and Munich 1987), vol. 2, pp. 265-268.
[3] *Technologie und Terminologie der Gewerbe und Künste bei Griechen und Römern*, vol. 4, Leipzig 1887, pp. 122-123, with references to Strabo and Diodorus.
[4] *Die Technik. Ein Lexikon der Vorzeit*, ..., op. cit., cols. 834-835.

[17] Again in 1919 Albert Neuburger[5] expressed the following view in connection with the use of the inclined plane in pyramid construction: “The inclined plane attained special importance by its use in the form of the screw, which is said to have been invented by Archimedes during an Egyptian journey. However, it is to be assumed that it had been in use there for a long time, for draining water in mines.” In 1956 E. J. Dijksterhuis,[6] in his work on Archimedes, also expressed the view that the machine was probably invented much earlier and that Archimedes merely first became familiar with it in Egypt.
In the same year A. G. Drachmann[7] reached a radically opposite conclusion: “ So I suggest that in the absence of even the faintest evidence to the contrary, and in the presence of both direct and indirect evidence of the most convincing character, it is safe to conclude that Archimedes really did invent the water-snail, and that it is called by rights the screw of Archimedes.”[8]
On the other hand, the historian of technology R. J. Forbes (1963),[9] who was certainly aware of the discussion on this question, restricts himself to the following statement: “It is said that Archimedes, when visiting Egypt about 220 B.C., saw such screws in action for pumping water onto the fields, and they are still in use throughout the Nile Valley for irrigation purposes.”
I myself consider it unlikely that Archimedes should have invented the screw pump on his journey to Egypt. In my view, its invention should be seen as the result of many years of experience the Egyptians had in the use of the inclined plane in pyramid construction and in water drainage in mines.[10] Archimedes may probably be given the credit for recognizing the importance of this achievement and for giving an impetus for its diffusion in Europe. Even Strabo[11] reports the use of the screw pump in Iberian mines.
The screw described by Vitruvius was driven by a treadmill.[12] In a mural[13] discovered in Pompeii in 1929 a screw pump seems to be propelled likewise by a treadmill.
Conrad Kyeser (1405) calls the screw “Testudo” and says that it was used for emptying trenches.[14] In his illustration[15] a crank serves as the drive.
Although there would have been the possibility for the screw pump to find its way to other parts of Europe via the Romans, there is some weight in the assumption that the type widely known in the Arabic world, particularly in Egypt, only reached the Western European countries in Islamic times via Northern Africa.[16] It is therefore surprising that Geronimo Cardano could claim in his *De subtilitate* (1500) that a smith from his hometown, Pavia, a certain Galeaz de Rubeis, had rediscovered the screw pump.[17]
A more advanced form of the instrument with a water wheel and two gearwheels is to be found among the drawings of instruments and machines made by Leonardo da Vinci:

[5] *Die Technik des Altertums*, Leipzig 1919, p. 211.
[6] Archimedes, Copenhagen 1956, pp. 21-22.
[7] *The Screw of Archimedes*, in: Actes du VIIIe Congrès international d’histoire des sciences Florence-Milan 3-9 septembre 1956, vol. 3, Florence 1958, pp. 940-943.
[8] Ibid., p. 943.
[9] *Studies in Ancient Technology*, vol. 7, Leiden 1963, p. 213.
[10] v. A. Neuburger, *Die Technik des Altertums*, op. cit., p. 211.
[11] Strabo, book 3, 147; *The Geography of Strabo* (Loeb), vol. 2, p. 45; Feldhaus, *Die Technik*, op. cit., col. 835.
[12] Book 10, chapter 11, v. *Vitruv: Baukunst*, transl. August Rode, 2 vols., Leipzig 1796 (repr. Zurich and Munich 1987), vol. 2, p. 267.
[13] v. R. J. Forbes, *Studies in Ancient Technology*, op. cit., vol. 7, p. 213.
[14] Conrad Kyeser, *Bellifortis*, after Feldhaus, *Die Technik*, op. cit., col. 835.
[15] Feldhaus, *Die Technik*, op. cit., col. 834.
[16] v. Charles Singer et al. (eds.), *A History of Technology*, op. cit., vol. 2, p. 677.
[17] Geronimo Cardano, *De subtilitate* libri XXI, in: *Hieronymus Cardanus. Opera omnia*. Facsimile repr. of the Lyons 1663 edition with an introduction by August Buck, vol. 3, Stuttgart - Bad Cannstatt 1966, p. 366; R. J. Forbes, *Studies in Ancient Technology*, op. cit., vol. 7, p. 215.

Fig. from *Leonardo da Vinci*, *op. cit.,* p. 480.

His screw-pump clearly reminds us of the screw-pump of his younger contemporary Taqīyaddīn (1553)[18] in Istanbul:

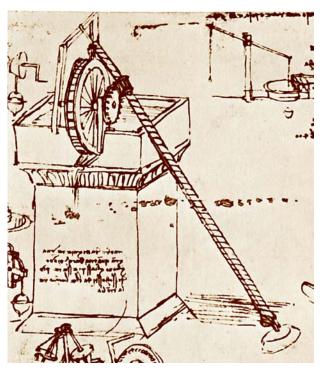
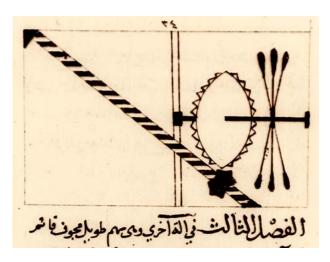
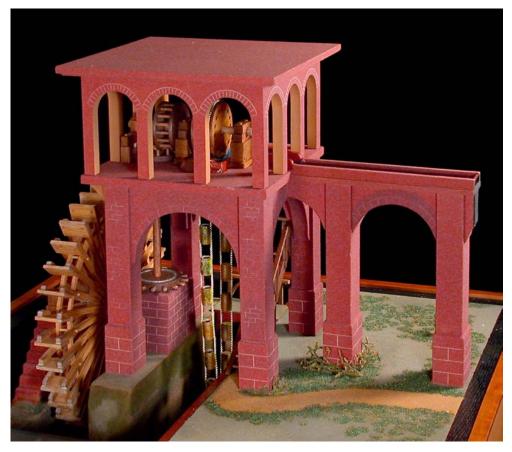



Fig. from Taqīyaddīn

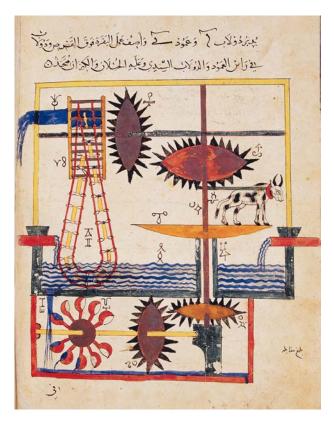
In my view Leonardo as well as Taqīyaddīn reproduce the type of screw-pump developed in the Arab-Islamic world.
The simple version rotated by a crank handle is still used today in Egypt for irrigating the fields.

Contemporary Egyptian screw-pump.

[18] Aḥmad Y. al-Ḥasan, *Taqīyaddīn wa-l-handasa al-mīkānīkīya al-ʿarabīya*, op. cit., p. 34; idem and D.R. Hill, *Islamic Technology*, p. 243.

Our model:
Wood and plastic.
Measurements:
71 × 64 cm.
Electric motor for demonstration.
(Inventory No. E 1.14)

Bucket Chain for Lifting Water

We know this device in a much simpler form from Vitruvius (d. ca. 25 B.C.).[1] The description of our instrument is from an anonymous Arabic book which was written apparently after the 6th/12th century. Its highly dubious title runs thus: "That is what Īrūn (Hero) extracted from the work of the two Greeks, Philon and Archimedes, viz. about the hauling of loads, the spheres, the waters, the bowls."[2] We may assume that the devices dealt with in this anonymous work were partly associated with the Greek scholars who are mentioned as the inventors. But what needs to be clarified is the question of the development which the instruments mentioned underwent later on, particularly in the Arab-Islamic world.

Our apparatus is a device for lifting water with two chains of buckets driven by a treadmill. A graphic reconstruction by Carra de Vaux[3] in 1903 turned out later to be not quite correct. In 1918 E. Wiedemann[4] called parts of his drawings "erroneous" or "arbitrary". We should not be surprised that the wrong version took root in the historiography of technology [20] and that, for instance, F. M. Feld-

[1] Book 10, chapter 9, v. *Vitruv: Baukunst*, op. cit., vol. 2, p. 262.

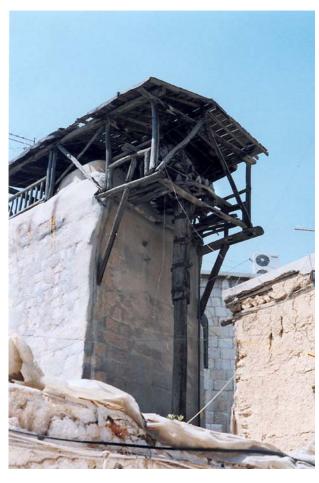
[2] v. Hans Schmeller, *Beiträge zur Geschichte der Technik in der Antike und bei den Arabern*, Erlangen 1922, p. 2 (repr. in: Natural Sciences in Islam, vol. 39, Frankfurt 2001, pp. 197-247, esp. p. 202).

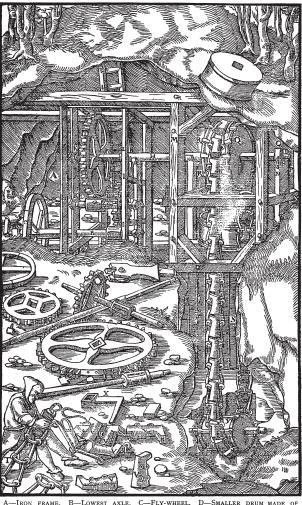
[3] Bernard Carra de Vaux, *Le livre des appareils pneumatiques et des machines hydrauliques, par Philon de Byzance, édité d'après les versions arabes d'Oxford et de Constantinople et traduit en français*, in: Notices et extraits des manuscrits de la Bibliothèque Nationale et autres bibliothèques (Paris) 38/1903/27-235, esp. pp. 209-212 (repr. in: Natural Sciences in Islam, vol. 37, Frankfurt 2001, pp. 101-309, esp. pp. 283-286).

[4] *Über Vorrichtungen zum Heben von Wasser in der islamischen Welt*, in: Beiträge zur Geschichte der Technik und Industrie (Berlin) 8/1918/121-154, esp. p. 151 (repr. in: *Gesammelte Schriften*, vol. 3, Frankfurt 1984, pp. 1483-1516, esp. p. 1513).

haus[5] speaks of three types of bucket chains for lifting water in the writings of Philon, which were driven either by an undershot water wheel, a crank handle or a treadmill.
A considerable improvement to the bucket chain for lifting water can be seen among the machines for lifting water described and illustrated by al-Ǧazarī[6] (ca. 600/1200):

Bucket chain water-lifting machine of al-Ǧazarī, *al-Ǧāmiʿ baina l-ʿilm wa-l-ʿamal an-nāfiʿ fī sināʿat al-ḥiyal*, facs. ed., Frankfurt 2002, p. 486.

He says that, the third type (see fig.) is a model to which he added the figure of a rotating wooden draught ox to mislead the onlooker; the mechanism is not driven by a draught animal, but by water power. Some of the water of a brook is channelled through a pipe into a basin, falls from there upon the flywheel that lies lower and flows off through a channel. All or part of the last third of the inflowing water goes into the buckets which transport it further upwards.
Our model represents the climax in the history of the development of the water-lifting bucket chain as known so far. It is more or less an improved variety of the device described by al-Ǧazarī. The main difference lies in the fact that here water power is used to drive a paddle wheel (instead of a bucket wheel) and that it involves flowing (instead of falling) water. However, the main prototype for our model is not an illustration or description in a literary source but an original water-lifting apparatus which was fully functional from the first half of the 7th/13th century until the middle of the previous century. Known by the name Manšaʾat Šaiḫ Muḥiyiddīn, it is situated on the banks of the Yazīd river in aṣ-Ṣāliḥīya, a locality in Damascus, and supplied a hospital and a mosque with water, until it ceased operation some 40 years ago (see the following page).
For constructing our model we used the detailed sketches and the description by A. Y. al-Ḥasan[7] from Aleppo of 1976.

[5] *Die Technik*, op. cit., col. 831; v. also A. P. Usher, A History *of Mechanical Inventions*, revised edition, New York 1954, p. 164.
[6] *al-Ǧāmiʾ baina l-ʿilm wa-l-ʿamal*, facs. ed. Ankara 1990, fol. 159 b; E. Wiedemann, *Über Vorrichtungen zum Heben von Wasser*, op. cit., pp. 141-143 (repr., op. cit., pp. 1503-1505); D. R. Hill, *The Book of Knowledge of Ingenious Mechanical Devices*, op. cit., pp. 182-183; idem, *Mechanik im Orient des Mittelalters*, in: Spektrum der Wissenschaft, July 1997, pp. 80-85, esp. pp. 80-81.
[7] *Taqīyaddīn wa-l-handasa al-mīkānīkīya al-ʿarabīya*, op. cit., pp. 55-70; v. also A. Y. Al-Hassan, D. R. Hill, *Islamic Technology*, op. cit., pp. 45-47.

Manša'at Šaiḫ Muḥyiddīn in Damascus.

The oldest known pictorial depiction of a similar device from Europe is to be found in the De re metallica[8] by Georgius Agricola (1556):

A—Iron frame. B—Lowest axle. C—Fly-wheel. D—Smaller drum made of rundles. E—Second axle. F—Smaller toothed wheel. G—Larger drum made of rundles. H—Upper axle. I—Larger toothed wheel. K—Bearings. L—Pillow. M—Framework. N—Oak timber O—Support of iron bearing. P—Roller. Q—Upper drum. R—Clamps. S—Chain. T—Links. V—Dippers. X—Crank. Y—Lower drum or balance weight.

Agricola, *De re metallica*, p. 173

From Leonardo da Vinci[9] (1519) we know of the water-lifting bucket chain driven by a crank handle:

[8] Georgius Agricola, *De re metallica*, translated by Herbert Clark Hoover and Lou Henry Hoover, New York, 1950, p. 173; A.P. Usher, *Machines and Mechanisms*, dans: *A History of Technology*, ed. Ch. Singer et al., op. cit., vol. 3, p. 325.

[9] *Leonardo da Vinci*, op. cit., p. 480.

Our model:
Wood and plastic.
Size: 68 × 52 cm.
With table and transparent hood.
Electric motor for demonstration.
(Inventory No. E 1.18)

Tympanum

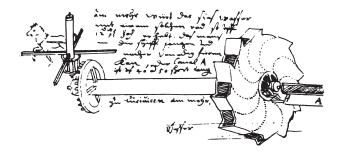
A drum-shaped water-lifting wheel, probably called *nāʿūra* or *sāqiya* in Arabic. In this type of water-lifting device spiral-shaped chambers turn around the axle of the wheel, collecting water, and transportng it to a tube in the hub of the wheel. It is suitable for lifting large quantities of water over small heights. It has a high degree of efficiency, and there are very few signs of wear and tear. The origin of this construction is unknown at present. A water wheel of this type, driven by two oxen, appears in the miniatures in the Paris manuscript of the *Maqāmāt* by al-Ḥarīrī (634/1237), Bibl. Nat., MS arabe 5847, fol. 69.[1] Water wheels like this are said to have been widespread in Egypt.[2]

[1] P.J. Müller, *Arabische Miniaturen,* Geneva 1979, plate 12.
[2] D.R. Hill, *Mechanik im Orient des Mittelalters,* in: Spektrum der Wissenschaft (Weinheim), July 1991, p. 81; idem, *Islamic Science and Engeneering*, Edinburgh 1993, pp. 95–96; A. Delpeche, F. Girard, G. Robine, M. Roumi, *Les norias de l'Oronte. Analyse technologique d'un élément du patrimoine Syrien*. Damascus 1997, p. 226; Thorkild Schiøler, *Roman and Islamic Water-lifting Wheels,* Odense University Press, 1973, pp. 78–79.

Illustration of a spiral-type water wheel, driven by oxen, miniature by Yaḥyā b. Maḥmūd al-Wāsiṭī in the *Maqāmāt* of al-Ḥarīrī (634/1237), Bibl. Nat. Paris, MS arabe 5847, fol. 69. After P. J. Müller, *Arabische Miniaturen*, Geneva 1979..

[24] The German architect Heinrich Schickardt (1558-1635) sketched a spiral-type water wheel near Milan during his Italian journey in 1598-1600 in connection with the local canals and water works.[3].

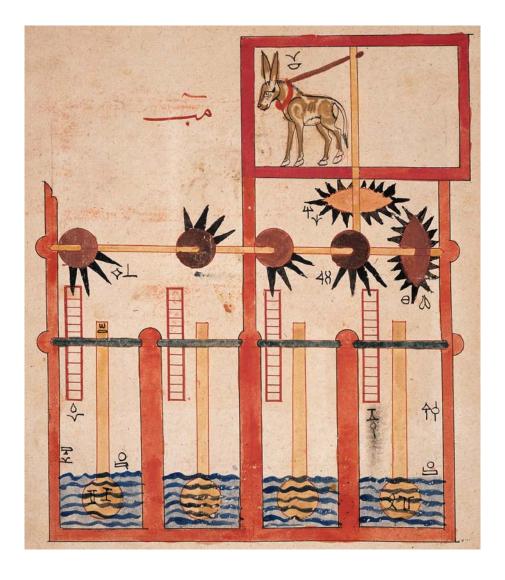
Sketch of the water-lifting works at Breta (Northern Italy) by H. Schickardt, 1600. After E. Kluckert.

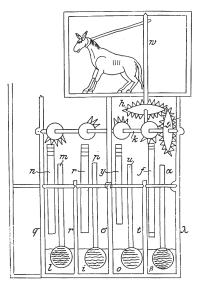
[3] v. E. Kluckert, *Heinrich Schickardt, Architekt und Ingenieur*, Herrenberg 1992, p. 47.

Installation for Lifting Water

from a pool wit a draught animal (mule-operating gin)

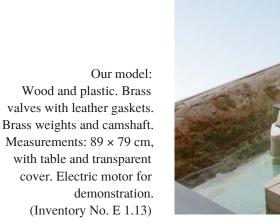
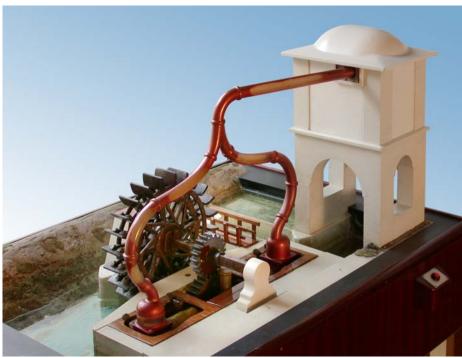
Our model:
Wood and plastic.
Dimension 145 × 80 cm with table and transparent hood.
Mechanism of hardwood, sealed.
Electric motor for demonstration.
(Inventory No. E. 1.07)

In the fifth part of his book on water-lifting devices,

Ibn ar-Razzāz al-Ǧazarī (ca. 600/1200) describes five types, the first four of which are driven by a draught animal. Our model represents the second[1] of the types described there.

"On the horizontal axle (k), which is mounted above the water level between the pillars (λ and q) and which is made to rotate by the draught animal by means of the vertical axle (w) and the gear-wheels (h and ϑ) four discs are set up which are provided with cogs for a quarter of their circumference, instead of just one single disc, which is provided partially with cogs. Their cog system is staggered by 90° from one to another. Under each of the four discs [26] there is a small axle each with the lantern

[1] *al-Ǧāmiʿ baina l-ʿilm wa-l-ʿamal*, facs. ed., Frankfurt 2002, pp. 478–483; Ankara 1990, pp. 310–314; D.R. Hill, *The Book of Knowledge of Ingenious Mechanical Devices*, op. cit., pp. 180–181.

Illustr. of the mule-operated gin in al-Ǧazarī, *al-Ǧāmiʿ bain al-ʿilm wa-l-ʿamal an-nāfiʿ fī ṣināʿat al-ḥiyal*, facs. ed., Frankfurt 2002, p. 481.

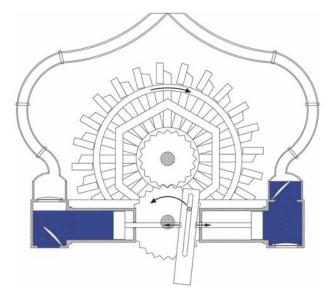
gear wheels (*n, r, y, f*) and the scoops (*lm, ip, ou, βα*). The individual axles, in their reciprocal extension, are mounted between a row of five pillars (*q, r, σ, t, λ*).”

“Because the cogs of the discs in one fourth of their circumference are staggered by 90° from one another, one of the same is in action all along so that the power of the draught animal is used more economically than with the arrangement of the previous section, where the animal works only during one-fourth of the revolution.” [2]

Redrawing of al-Ǧazarī’s illustration by E. Wiedemann.

[2] Translated by E. Wiedemann, *Über Vorrichtungen zum Heben von Wasser in der islamischen Welt*, in: Beiträge zur Geschichte der Technik und Industrie 8/1918/121–154, esp. pp. 140–141 (repr. in: *Gesammelte Schriften*, vol. 3, pp. 1483–1516, esp. pp. 1502–1503).

Pumping Station

driven by a water wheel

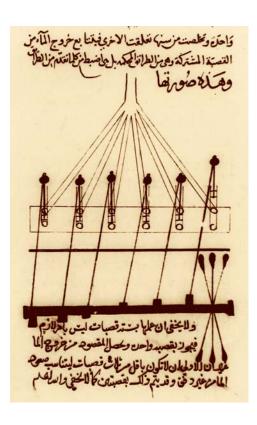
Our model:
Wood and plastic. Brass valves with leather gaskets. Brass weights and camshaft. Measurements: 89 × 79 cm, with table and transparent cover. Electric motor for demonstration.
(Inventory No. E 1.13)

After the machines driven by draught animals, al-Ǧazarī[1] (ca. 600/1200) describes a machine that lifts water by means of a wheel from a river to a height of up to 20 ells (ca. 11 m). This machine is also listed by Taqīyaddīn[2] among the hydraulic appliances.

The system uses the natural current of a river. A water wheel standing in the current produces a uniform rotary motion which continues into a shaft. A gearwheel attached to the shaft transmits the motion to another gearwheel, to which a pivot is fastened. A piston rod which is loosely connected to the pivot transforms the rotary motion mechanically into a thrusting motion. Two pistons connected to the piston rod use the horizontal thrusting motion to suck in water from the river and to pass it on to a chamber each. With each motion one piston sucks in water, the other displaces it. The chambers have two valves each, one entry-valve and one exit-valve. After the piston has sucked the water in, the entry-valve closes the chamber, during the displacement the water reaches the rising pipe, which is attached to the chamber. From there water cannot flow back when the piston moves in the opposite direction, since the exit-valve closes. Meanwhile the second pump sucks up water. Thus a uniform stream of water flows into the rising pipe which in turn leads to a reservoir from where the water can be diverted to the houses or to the fields.

Drawing of the construction of al-Ǧazarī's pump.

[1] al-Ǧazarī, op. cit., pp. 321-327; D. R. Hill, op. cit., pp. 186-189; E. Wiedemann, *Über Vorrichtungen zum Heben von Wasser*, op. cit., pp. 145-147 (repr., pp. 1507-1509).
[2] Aḥmad Y. al-Ḥasan, *Taqīyaddīn wa-l-handasa al-mīkānīkīya al-ʿarabīya*, Aleppo 1976, repr. 1987, facs., pp. 29-32.

Pump with six pistons

by Taqīyaddīn (1553)

Our model:
Wood and plastic. Brass valves with leather gaskets. Brass weights and camshaft.
Measurements: 89 × 79 cm, with table and transparent cover.
Electric motor for demonstration.
(Inventory No. E 1.13)

The Ottoman universal scholar of Arab descent Taqīyaddīn Muḥammad b. Maʿrūf (d. 993/1585) describes in his book on pneumatic devices (*aṭ-Ṭuruq as-sanīya fi l-ālāt ar-rūḥānīya*[1]), which he wrote in 960/1553, two versions of water pumps, one of which lifts water from a river by means of two pistons and the other with six pistons. The first is already known to us thanks to the book by Ibn ar-Razzāz al-Ǧazarī (see the preceding pump-works). The second version appears to have emerged in the phase of development after al-Ǧazarī. The natural current of a river drives the system through a water wheel. The six pumps convey the water up to a certain height, from where it can be transmitted further.

Page from Taqīyaddīn, *aṭ-Ṭuruq* …, MS Dublin, Chester Beatty Lib. 5232.

[1] ed. A.Y. al-Ḥasan in *Taqīyaddīn wa-l-handasa al-mīkānīkīya al-ʿarabīya*, op. cit., pp. 36–38; A.Y. al-Hassan, D.R. Hill, *Islamic Technology*, op. cit., pp. 50–52.

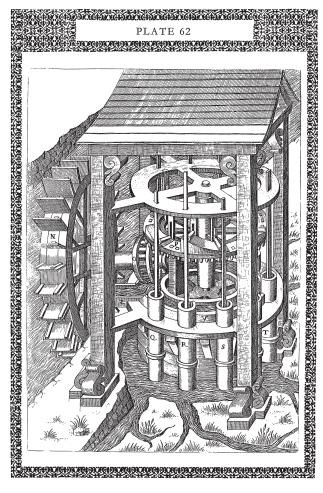
In this model the rotary motion generated by the water wheel is transmitted to a camshaft. [29] The cams operate individual levers through which the rotary motion is converted to a linear motion. They are set up on the shaft in a staggered manner so that the water power is distributed uniformly. When one of the levers is operated it causes a piston and a weight attached to it to be pressed upwards. A vacuum is thereby created in the pump chamber belonging to it, as a result of which the entry valve opens and water is sucked in. When the cam has released the lever once again, the piston is pressed downwards by the weight attached to it. This closes the entry valve, and the water is pumped upwards through the rising pipes. While this is happening, an exit valve opens and closes at the end of the process once again, thus preventing the water from flowing back. Moreover, the repeated sucking of the pump creates an air blockage through which the vacuum can be built up again and water can be sucked in. Because of the fact that six pumps are driven one after the other a continuous flow of water is guaranteed. A similar water-lifting works with several pistons is described and illustrated in the book by Agostino Ramelli[2] in 1588.

Water rising while the piston is sinking.

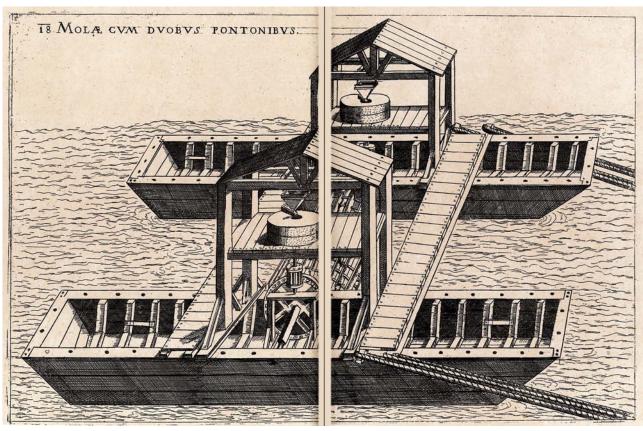
PLATE 62

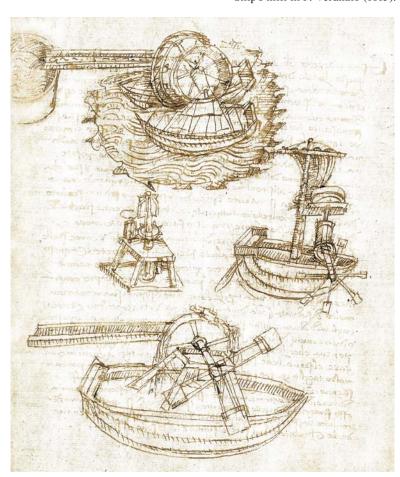
Pumping station by A. Ramelli (1588).

Water being sucked in while the piston is rising.

[2] *The Various and Ingenious Machines of Agostino Ramelli. A Classic Sixteenth-Century Illustrated Treatise on Technology*. Translated from the Italian and French with a biographical study of the author by Martha Teach Gnudi. Technical annotations and a pictorial glossary by Eugene S. Ferguson, Baltimore 1976, p. 184 and plate. 62.

Ship's Mill

The three "sons of Mūsā" (Banū Mūsā) speak of a ship's mill (*ʿaraba*) in their treatise on a "wind instrument that plays by itself"[1] written around the middle of the 3rd/9th century (on this, see part I of the Museum Catalogue: Musikinstrumente, p. 202 ff.). In the 4th/10 th century the geographer Ibn Ḥauqal[2] reports that on the Tigris near Mosul there were ship's mills (here pl. *ʿurūb*) "the like of which one gets to see rarely anywhere in the world." They were made of wood and iron; secured by iron chains, they lay in the current in the middle of the river and were equipped with two pairs of mill-stones each. The reports collected by E. Wiedemann show that ship's mills were widespread in the Islamic world for centuries.

Our model:
Ship of hardwood, with watertight seal.
Length: 80 cm.
Water wheels attached on the sides (driven by an electric motor for demonstration purposes), connected to the mill-stones (here only one pair) via gear transmission. Tub of plastic material in a hardwood table.
Measurements: 120 × 86 × 80 (height) cm.
(Inventory No. E 1.03)

[1] *al-Āla allatī tuzammiru bi-nafsihā*, ed. L. Cheikho, in: al-Mašriq (Beirut) 9/1906/444-458, esp. p. 454 (repr. in: Natural Sciences in Islam, vol. 42, Frankfurt 2001, pp. 19-33, esp. p. 29), v. E. Wiedemann, *Über Schiffsmühlen in der muslimischen Welt*, in: Geschichtsblätter für Technik, Industrie und Gewerbe (Leipzig) 4/1917/25-26 (repr. in: *Gesammelte Schriften*, vol. 2, pp. 863-864).
[2] *Kitāb Ṣūrat al-arḍ*, ed. J. H. Kramers, Leiden 1939, vol. 1, p. 219.

Ship's mill in F. Veranzio (1615).

In the first half of the 15th century Mariano Taccola drew sketches depicting the component parts of ship's mills (fig. on the right).[3] A detailed illustration of a mill with two pairs of mill-stones, as described by Ibn Ḥauqal, is to be found in the Machinae novae of 1615 by Fausto Veranzio[4] (fig. above).

From D. Taccola, *De ingeneis*.

[3] Mariano Taccola, *De ingeneis*, vol. 2, facs. Wiesbaden 1984, fol. 104 v.
[4] Fausto Veranzio, *Machinæ novæ*, Munich 1965, No. 18.

Windmill

Our model:
Wood, lacquered.
Height: 60 cm.
5 sails of linen
on a vertical axis inside.
Electric fan for demonstration.
(Inventory No. E 1.04)

Windmills (*raḥā*, pl. *arḥā*) were apparently widespread in Persia even before the advent of Islam, and the knowledge of them also reached other parts of the Islamic world quite early. As the historian Muḥammad b. Ǧarīr aṭ-Ṭabarī (d. 310/923) reports in his annals,[1] ʿUmar, the second Caliph (ruled 13/634-23/644), is supposed to have said to the Persian Abū Luʾluʾa, who was known as a painter, joiner and metalworker and who became later the assassin of this Caliph: “It was reported to me that you claimed you could build a mill that grinds with wind power if I desired it,” to which Abū Luʾluʾa answered: “Yes, that is true.” Then ʿUmar is supposed to have said: “Then build me such a mill.”[2]

References to windmills in Siǧistān (or Sīstān, North-Eastern Persia) are to be found in the Arabic writings of several geographers like al-Iṣṭaḫrī (1st half of the 4th/10 th cent.) or his younger colleague Ibn Ḥauqal.[3] Ruins of such mills are to be found in this area until today.

Windmills in Sīstān, North-East Persia, ill. from *al-ʿUlūm fi l-islām*, Tunis 1978, p. 204.

[1] *Taʾrīḫ ar-rusul wa-l-mulūk*, ed. M. J. Goeje, series 1, vol. 5, Leiden 1879 (repr. ibid., 1964), p. 2722; E. Wiedemann, *Zur Mechanik und Technik bei den Arabern*, in: Sitzungsberichte der Physikalisch-medizinischen Sozietät (Erlangen) 38/1906/1-56, esp. p. 44 (repr. in: *Aufsätze zur arabischen Wissenschaftsgeschichte*, vol. 1, pp. 173-228, esp. p. 216).

[2] For another version of this incident, v. al-Masʿūdī, *Murūǧ aḏ-ḏahab wa-maʿādin al-ǧauhar*, ed. C. Barbier de Meynard, Paris 1864, vol. 4, p. 227, v. ibid., vol. 2, p. 80; E. Wiedemann, op. cit., p. 44 (repr., p. 216).

[3] E. Wiedemann, op. cit., p. 217.

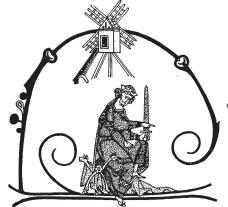
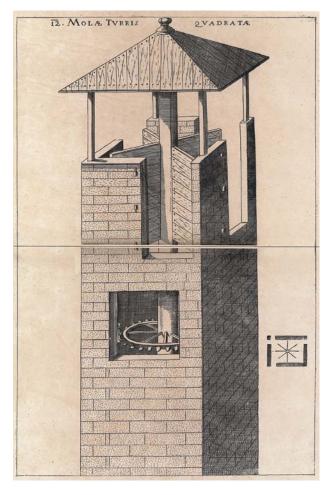



Illustration of the windmill from ad-Dimašqī.

To the geographer Šamsaddīn Muḥammad ad-Dimašqī (d. 727/1327) we owe the most detailed description of a windmill together with an illustration.[1] It reads thus in translation: “In Siǧistān there is an area where wind… are frequent. The people living there use the winds for turning the mills… To construct the mills which turn in the wind they proceed as follows. They erect [a building] as high as a minaret, or they take a high mountain top or a similar hill or a castle tower. On these they construct one room above the other. In the upper room there is the mill (*raḥā*) that turns and grinds, in the lower one there is a wheel (*daulāb*) that is turned by the wind, which has been harnessed. When the wheel below is turning, the mill on the wheel above turns. No matter what kind of wind blows, those mills turn, although only a single [mill]stone is present, and the picture of it looks like this …”
“When they have carried out the construction of the two rooms as shown in the illustration, they make four embrasures (*marmā*) in the lower room like the embrasures in the walls (*aswār*), only here the embrasures are the other way round, as their broad part is turned to the outside and their narrow part to the inside, [thus forming] a channel for the air so that through it the air enters inside with force as in the goldsmith’s bellows. The broad end is situated towards the mouth and the narrow one towards the inside so that it is more suitable for the entry of the air which enters into the room of the mill, from whichever area the wind may be blowing.”[5]
With great probability the windmills of Persian origin found their way to the west of the Islamic world quite early. The geographer Abū ʿAbdallāh al-Ḥimyarī from Moorish Spain (writing in 866/1461) mentions, among the special features of the port of Tarragona, the existence of mills driven by wind power.[6]

Windmill in the Canterbury Psalter (1270) from Ch. Singer (ed.), *History of Technology*, vol. 2, p. 623.

[4] *Nuḫbat ad-dahr fī ʿaǧʾib al-barr wa-l-baḥr*, ed. A. Mehren, *Cosmographie de Chems-ed Din ... ad-Dimichqui*, Petersburg 1866 (repr. Islamic Geography, vol. 203, Frankfurt 1994), pp. 181-182; French transl. A. F. Mehren, *Manuel de la cosmographie du Moyen-Âge*, Copenhagen 1874 (repr. Islamic Geography, vol. 204, Frankfurt 1994), p. 247.

[5] Translated from E. Wiedemann, *Zur Mechanik* …, op. cit., p. 46 (repr. p. 218).

[6] *ar-Rauḍ al-miʿṭār fī ḫabar al-aqṭār*, ed. E. Lévi-Provençal, *La Péninsule ibérique au Moyen-Âge*, Leiden 1938, p. 126; French transl. ibid., p. 153.

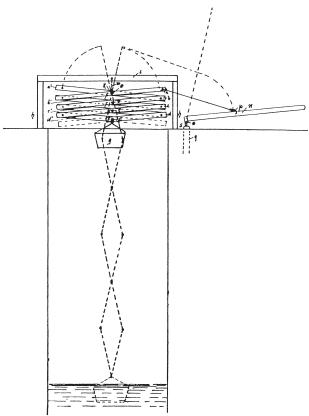
‹Horizontal› windmills from Veranzio (1615).

As far as further diffusion of this type is concerned, there is some evidence in favour of the assumption[7] that it reached China from about the 7th/13th century onwards. The earliest known development of the windmill in Europe goes back to the 12th century. A book of psalms written in 1270 in Canterbury shows the first English illustrations of a mill with vertical arms.[8]
Several drawings of the "Persian" type are to be found among the *Machinae novae* by Fausto Veranzio (1615).[9]

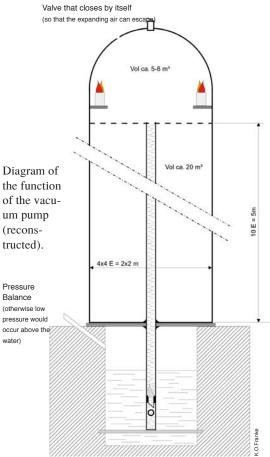
It is still an open question whether this type of windmill was in fact really constructed in Europe.[10] According to the description by ad-Dimašqī which we reproduced above, the millstone was to be found in the upper part of the mill, while the wind apparatus was installed below. Further development led to a reversal of this order, as newer illustrations show (see fig. above).[11]
During his journey through Persia Sven Hedin counted as many as 75 windmills of this type as against a total number of 400 houses in the small town of Neh in Sīstān. (cf. fig. above, p. 32).[12]

[7] Joseph Needham, *Science and Civilisation in China*, vol. 4, part 2, Cambridge etc. 1965, p. 560
[8] Rex Wailes, *A Note on Windmills*, in: Charles Singer et al. (eds.), *A History of Technology*, vol. 2, Oxford 1956, pp. 623-628, esp. p. 623; Hans E. Wulff, *The Traditional Crafts of Persia*, Cambridge (Mass.) 1966, p. 286.
[9] *Machinae novae*, Munich 1965, No. 11, 13.

[10] v. also R. J. Forbes, *Studies in Ancient Technology*, vol. 2, Leiden 1955, pp. 111-116; Hugo Th. Horwitz, *Über das Aufkommen, die erste Entwicklung und die Verbreitung von Windrädern*, in: Beiträge zur Geschichte der Technik und Industrie 22/1933/93-102; A. Y. al-Hassan, D. R. Hill, *Islamic Technology*, op. cit., pp. 54-55.
[11] H. E. Wulff, op. cit., pp. 286-289.
[12] *Eine Routenaufnahme durch Ostpersien*, Stockholm 1926, vol. 2, p. 141; cf. H. E. Wulff, op. cit., p. 286.

Lever in form of scissors

Our model:
Wood, laminated,
and brass.
Height 57 cm.
(Inventory No. E

The device known in German-speaking areas as ‹Nuremberg scissors› (Nürnberger Schere) is described in the anonymous Arabic book which was mentioned above (p. 19), the content of which is partly associated with Greek scholars like Archimedes, Philon and Hero, but also with Alexander the Great. Hans Schmeller,[1] who is inclined to see in the author an Arab living in Syria or in Iraq, translated[2] the description of this device from the Arabic into German and depicted it graphically. According to the text, by means of this device one single man should be able to lift water weighing 500 *raṭl* (ca. 220 kg) in one go.[3]
Feldhaus[4] mentions that the Nuremberg scissors can also be used as a pontoon bridge, ladder, or scissors for the transmission of motion in machinery.
For the construction of our model we used the drawing by H. Schmeller.

Drawing by H. Schmeller, *Beiträge zur Geschichte der Technik*, p. 9 (repr., p. 209).

[1] *Beiträge zur Geschichte der Technik in der Antike und bei den Arabern*, op. cit., p. 2 (repr., op. cit., p. 202).
[2] ibid., pp. 9-10 (repr., op. cit., pp. 209-210).
[3] *Die Technik*, op. cit., col. 910.
[4] *Die Technik*, op. cit., col. 910.

Apparatus
for lifting water by means of fire

Valve that closes by itself
(so that the expanding air can escape)

Vol ca. 5-8 m³

Vol ca. 20 m³

10 E = 5m

4x4 E = 2x2 m

Pressure Balance
(otherwise low pressure would occur above the water)

K.O.Franke

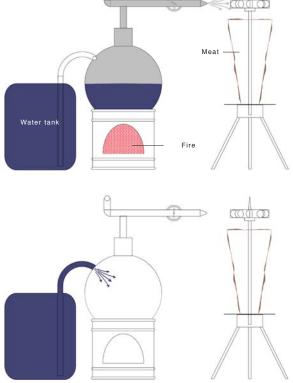
Diagram of the function of the vacuum pump (reconstructed).

Our model:
Wood, laminated, plastic, copper and brass, tallow candle.
Height: 61 cm.
(Inventory No. E 1.23)

Among the four extant manuscripts of the anonymous anthology[1] which describe, with much variation, Greek, pseudo-Greek and Arabic inventions in the field of technology, the Codices Gotha 1348 and Leiden, Warn. 449 offer an apparatus for lifting water by means of fire.[2]

The function of the pump, which we represent in a model of greatly reduced size, is described by H. Schmeller thus: "As a consequence of the increase in temperature due to the burning of naphthalene lamps, the air in the upper space is expelled or consumed. In the subsequent cooling, the pressure decreases and the external air pressure pushes the water in the channel upwards."[3] According to the description in our source, this device is supposed to be able to lift water from a 5 to 25 m deep well. The question must remain open to what extent practical use could be made of this procedure.

[1] Istanbul, Ayasofya 3187, Oxford, Bodl. Marsh 669, Gotha 1348, Leiden, Warn. 499 (= or. 499, v. P. Voorhoeve, *Handlist of Manuscripts*, Leiden 1957, pp. 116-117).

[2] v. H. Schmeller, *Beiträge zur Geschichte der Technik in der Antike und bei den Arabern*, op. cit., pp. 26 ff. (repr. in: Natural Sciences in Islam, vol. 39, pp. 197-247, esp. 226-227).

[3] ibid., p. 27.

Our model:
Copper, brass, stainless steel.
Diameter of the boiler 30 cm.
With a heating spiral and
shut-off valve.
(Inventory No. E 1.25)

Steam-driven

Apparatus for turning roast meat

Meat

Water tank

Fire

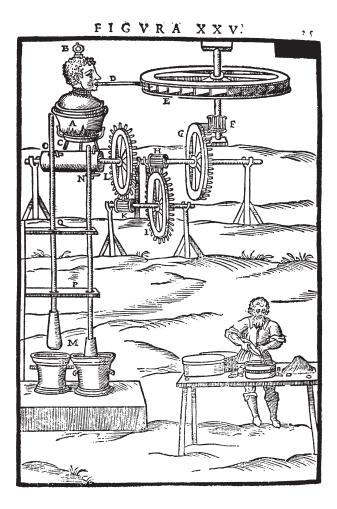
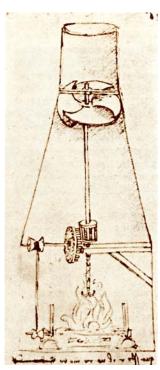
The Ottoman astronomer and engineer Taqīyaddīn describes three devices for turning a roasting spit in the sixth chapter of his *Kitāb aṭ-Ṭuruq as-sanīya fi l-ālāt ar-rūḥānīya* (953/1546). The first device is turned by harnessing steam power. The second is driven by a weight whose movement is regulated by a hot air turbine. The third one was built according to the principle of transferring a relatively low power via gearwheels which are set in motion by a hand crank.

Diagrams of the cross sections through our model..

Fig. 1 (above): Reconstruction of the steam cart by P.-M. Grimaldi.

Fig. 2 (on the right): Sketch of the steam-driven wheel by Giovanni Branca.

In our model of the first device the spit is moved, together with a paddlewheel-like turbine, by the steam, which escapes through [38] a pipe from a closed boiler which is heated. According to Taqīyaddīn's description, the water in the boiler is replenished by putting the mouth of the pipe into a water container. That was sufficient to fill the cauldron once again. Taqīyaddīn reports that this type of steam device was in widespread use in his day. In 1629 Giovanni Branca[1] drew the sketch of a steam-driven wheel (see fig. 2) in which the steam blows from a metal mouth towards a paddlewheel. The device is designed to set in motion a pounding machine.[2]

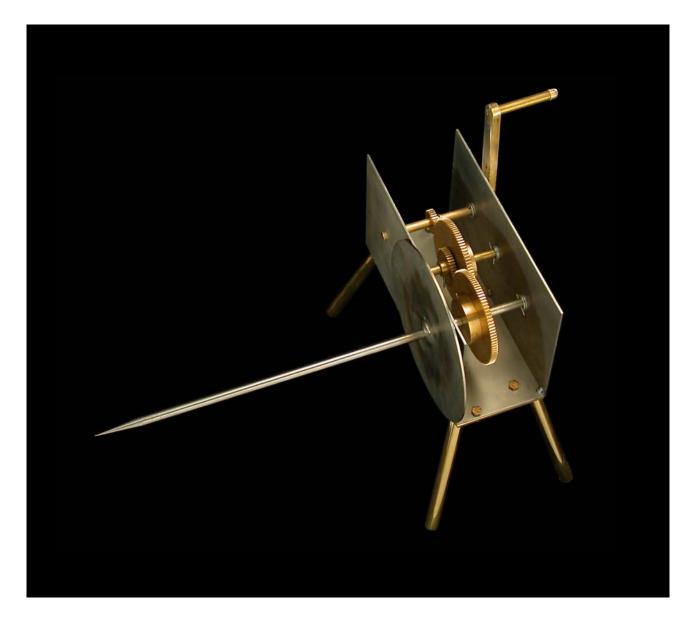
The utilization of steam power apparently made a further advance in the work of Philippe-Marie Grimaldi. Around 1671, he is said to have demonstrated a cart driven by steam power to the Manchurian Emperor K'ang Hsi. A reconstruction (see fig. 1) produced in the 19th century by Giovanni Canestrini (1835-1900) is preserved in the Museo Nazionale della Scienza e della Technica at Milan.[3]

[1] *Le machine. Volume nuovo e di molto artificio da fare effetti maravigliosi* ..., Rome 1629, fig. XXV.
[2] v. F. M. Feldhaus, *Die Technik*, op. cit., p. 182.

[3] v. J. Needham, *Science and Civilisation in China*, op. cit., vol. 4, part 2, pp. 225-228.

Apparatus for turning roast meat

by means of hot air

Our model:
Copper, brass, stainless steel.
Diameter of the shaft 30 cm.
With heating spiral and shut-off valve.
(Inventory No. E 1.26)

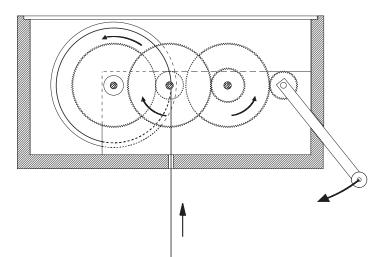
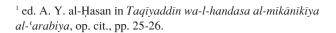
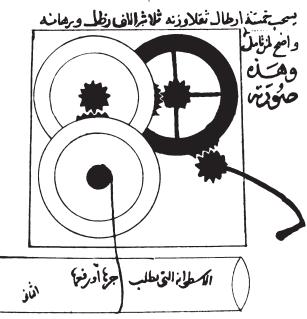
Illustr. from *Leonardo da Vinci*, op. cit., p. 503.

Taqīyaddīn describes only briefly the second type of device for turning a roast spit, which was as common as the first type at that time. Instead of the steam turbine, here the hot air rising up through the chimney is used to turn the spit. As in the case of bucket conveyors for water, additional energy was supplied by a lead weight. One can probably imagine this as involving the weight running over a pulley as in a clock. The power transferred through a gear system to the spit will therefore not have been adequate to turn the roast sufficiently fast.

The Codex Atlanticus (fol. 5) of the work by Leonardo da Vinci[1] preserves the sketch of an apparatus for turning roast meat (see illustration) which is powered by smoke or rather by the heated air ascending from the fire beneath the roast spit.[2] This sketch, in which the gear transmission can also be seen, was very useful for our reconstruction. I doubt, however, whether an apparatus built according to the sketch would function because apart from the hot air no other source of energy is apparently provided for.

[1] *Leonardo da Vinci*, op. cit., p. 503.
[2] Theodor Beck, *Beiträge zur Geschichte des Maschinenbaues*, Berlin 1899, pp. 425-426.

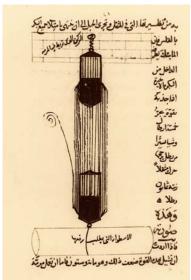
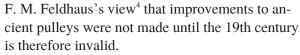
Apparatus for turning roast meat

with a crank and gear drive

Our model:
Brass, stainless steel.
Height: 35 cm.
(Inventory No. E 1.27)

After his description of the first two mechanical devices for turning roast meat which he had first seen in Istanbul, Taqīyaddīn adds that he and his elder brother had invented an instrument there in 953/1546 which was supposed to be easier to transport than the conventional apparatus. The new apparatus for turning roast meat functions with a crank and a system of four gearwheels which produce a transmission ratio of 1:10 and thus make it easy to turn a heavy roast slowly.

Our model:
Wood and brass,
Copper weight (8 kg)
(Inventory No. E 1.12)

Hoist with gear drive

In his book on pneumatic devices (*aṭ-Ṭuruq as-sanīya fi l-ālāt ar-rūḥānīya*[1]) written in 960/1553, the Ottoman scholar Taqīyaddīn describes a gear wheel system (*ad-dawālīb al-mutadāḫilat al-asnān*) which makes it possible to lift a weight of 3000 *raṭl* (ca. 1450 kg) by the application of one-thousandth of the power. In our model with a drive consisting of several steps the transmission ratio is 1:150.

Fig. from:
Taqīyaddīn, *aṭ-Ṭuruq as-sanīya*, p. 26.

[1] ed. A. Y. al-Ḥasan in *Taqīyaddīn wa-l-handasa al-mīkānīkīya al-ʿarabiya*, op. cit., pp. 25-26.

Block and tackle

Of the types of block and tackle dealt with in Arabic books on technology or in monographs,[1] the Ottoman scholar Taqīyaddīn[2] describes a fairly advanced type with which a certain load can be lifted with one-sixteenth of the power normally needed. For this he uses twice eight wooden pulleys and combines them in the form of a cylinder. There is a similar block and tackle in Leonardo da Vinci's sketches:[3]

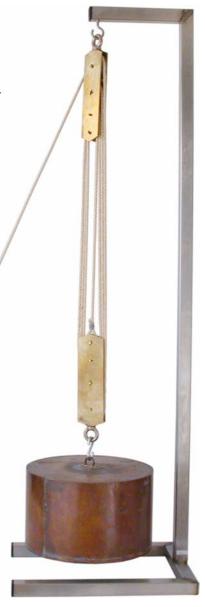
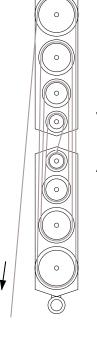
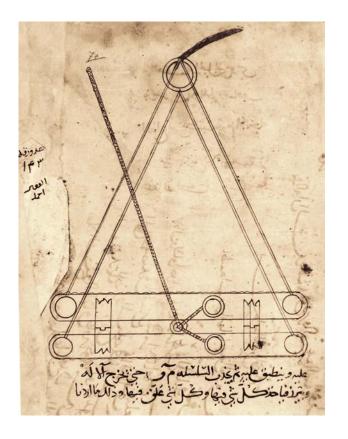
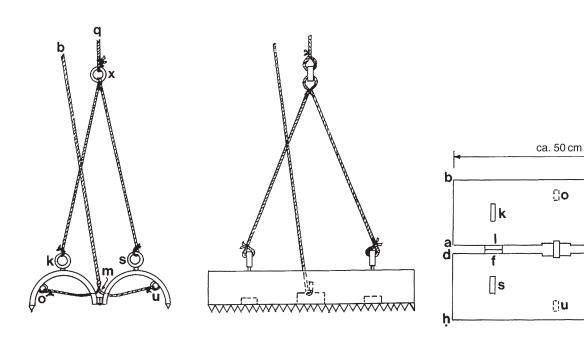
Our model:
Brass and steel.
Copper weight ca. 15 kg.
Frame of stainless steel,
Height: 130 cm.
(Inventory No. E 1.11))

Page from: Taqīyaddīn, *aṭ-Ṭuruq as-sanīya*, MS Dublin, Chester Beatty Lib. 5232

Fig. from: *Leonardo da Vinci*, p. 490.

F. M. Feldhaus's view[4] that improvements to ancient pulleys were not made until the 19th century is therefore invalid.
In our model we used only half the number of pulleys envisaged in the original.

[1] They are dealt with using the terms *bakra* ("reel") or *ǧarr al-aṯqāl* ("pulling of weights"), v. E. Wiedemann, *Zur Mechanik und Technik bei den Arabern*, in: Sitzungsberichte der Physikalisch-medizinischen Sozietät (Erlangen) 38/1906/1–56, esp. p. 20 (repr. in: *Aufsätze zur arabischen Wissenschaftsgeschichte*, vol. 1, pp. 173–228, esp. p. 192).
[2] *Kitāb aṭ-Ṭuruq as-sanīya fi l-ālāt ar-rūḥānīya*, facs. ed. A.Y. al-Ḥasan, *Taqīyaddīn wa-l-handasa al-mīkānīkīya al-ʿarabīya*, op. cit., pp. 27–28.
[3] *Leonardo da Vinci*, p. 490.
[4] *Die Technik*, op. cit., col. 332.

Apparatus
for lifting objects from water (grab dradger)

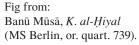
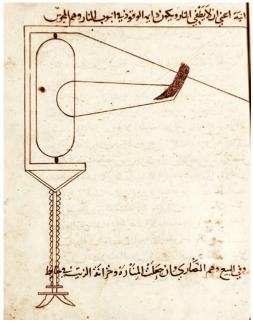
Our model:
Brass cylinder,
Length: 50 cm.
Folds open by means of two hinges.
Brass chains.
(Inventory No. E 1.05)

The three sons of Mūsā b. Šākir (Muḥammad, Aḥmad and al-Ḥasan), known as Banū Mūsā ("sons of Mūsā"), who lived in the first half of the 3rd/9th century, describe in their *Kitāb al-Ḥiyal*[1] as the hundredth device an apparatus which serves to lift objects from water. They say: "We want to show how make an instrument with which a person, when he lets it down, can take out material (*ǧauhar*) from the ocean and those objects that have fallen into wells and those that have sunk into rivers and oceans. For this purpose we construct the two halves *abjz* and *wḥde* of a [hollow] cylinder of copper, which are equal to one another; if one half exceeds the other a little in weight then that is better for the present purpose so that one half may take the other one into it (devour it) and [the second one] may enter into the first one a little. Each of the two cylinders should be 1 ell long or longer... One half of the cylinder is adjusted (split) according to the other so that there is not even a small gap between them. Then two hinges (*narmāḏaǧatān*) are attached to them ..."[2] When the apparatus is lowered into water with the help of the four chains that are attached on the outside, the grab cylinder opens. When it reaches the ground, it is pulled up again by means of the chain which is attached in the middle. As a result the cylinder closes and traps the objects which it has enclosed.

[1] ed. Aḥmad Y. al-Ḥasan, Aleppo 1981, pp. 376-379; Engl. transl. Donald R. Hill, *The Book of Ingenious Devices*, Dordrecht etc. 1979, pp. 242-243.

[2] German transl. E. Wiedemann (with slight changes) in: Apparate aus dem Werk *fi l'-Ḥijal der Benû Mûsâ* (*Zur Technik bei den Arabern*. 7), in: Sitzungsberichte der Physikalisch-medizin ischen Sozietät (Erlangen) 38/1906/341-348, esp. pp. 343-345 (repr. in: *Aufsätze zur arabischen Wissenschaftsgeschichte*, vol. 1, pp. 306-313, esp. pp. 308-310).

Grab dredger of the Banū Mūsā (MS Berlin).

Construction diagrams
(D. R. Hill after E. Wiedemann)

Grab cylinder opened
(end view)

Grab cylinder opened
(side view)

Vertical section
(without ropes)

a Lamp
that does not go out even in strong wind

Our model:
Brass
Height: 63 cm.
(Inventory No. E 1.16)

Fig from:
Banū Mūsā, *K. al-Ḥiyal*
(MS Berlin, or. quart. 739).

Around the middle of the 3rd/9th century the Banū Mūsā (Muḥammad, Aḥmad and al-Ḥasan b. Mūsā b. Šākir) described, in their *Kitāb al-Ḥiyal*,[1] a lamp[2] that does not go out even when it is used in a strong wind.

Our model was constructed according to the description and the illustration by the Banū Mūsā and as interpreted by E. Wiedemann and D. Hill.
The half-cylinder which encloses the lamp is inserted in a frame in such a way that it turns easily. The brass flag attached to it causes the half-cylinder to turn with the closed side towards the wind whenever there is a movement of air, with the effect that the lamp cannot be extinguished by the draught of air. The easy movement of the bearings plays a decisive role so that the flag can turn even in a soft breeze.

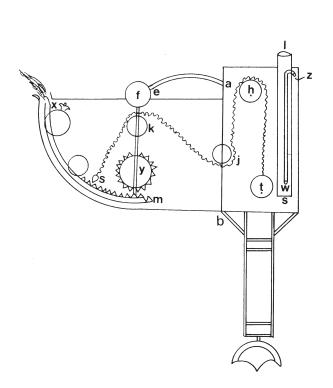
[1] ed. Aḥmad Yūsuf al-Ḥasan, Aleppo 1981, esp. pp. 372-373.
[2] Eilhard Wiedemann, *Über Lampen und Uhren* (Beiträge zur Geschichte der Naturwissenschaften. XII), in: Sitzungsberichte der Physikalisch-medizinischen Sozietät (Erlangen) 39/1907/200-225, esp. pp. 204-205 (repr. in: *Aufsätze zur arabischen Wissenschaftsgeschichte*, vol. 1, pp. 351-376, esp. pp. 355-356); *The Book of Ingenious Devices (Kitāb al-Ḥiyal) by the Banū (sons of) Mūsā bin Shākir*. Translated and annotated by Donald R. Hill, Dordrecht, Boston, London 1979, pp. 238-239.

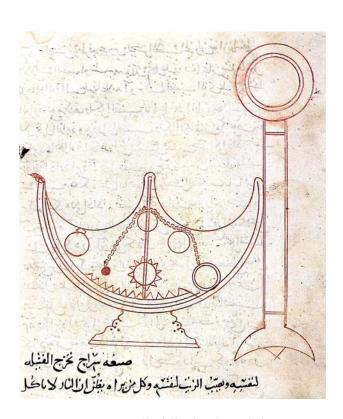
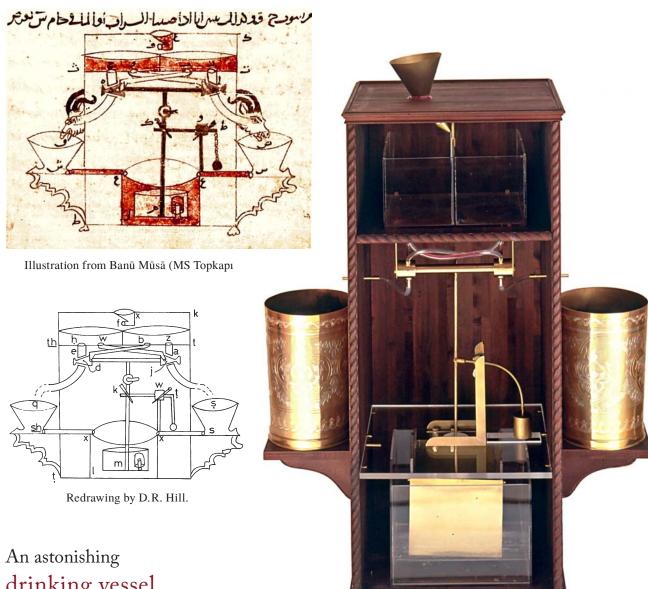
God's Lantern

(Eternal light)

Our model:
Brass, height: 60 cm.
Glass window for viewing.
Wooden wall, height 80 cm.
(Inventory No. E 1.06)

The Arabic term *sirāǧ Allāh* ("God's lantern") designates an oil-lamp "whose wick comes up by itself and whose oil flows into it by itself. Everyone who sees it believes that absolutely none of the oil and the wick is consumed."[1]
The three "sons of Mūsā" (Banū Mūsā) described a lamp like this in the first half of the 3rd/9th century in their *Kitāb al-Ḥiyal*.[2] It could burn for days without anyone having to push the wick forward. The oil continued to flow automatically, seemingly without any decrease in quantity.
A sophisticated technical system ensures that the lamp replenishes itself from a concealed reservoir of oil. In this reservoir a vacuum is created after the filling through the valve *lwz* (see fig. p. 47), which prevents the oil from flowing off through the spout *e*. As soon as the sinking level of oil uncovers the opening *j*, the vacuum is removed, oil flows into the lamp until the opening submerges again and renews the vacuum in the reservoir. In this way the actual oil supply in the lamp remains always constant. The float *ṭ* causes the wick to be automatically pushed forward when the level of oil in the reservoir drops.

[1] E. Wiedemann, *Über Lampen und Uhren*, in: Sitzungsberichte der Physikalisch-medizinischen Sozietät (Erlangen) 39/1907/200-225, esp. 203-204 (repr. in: *Aufsätze zur arabischen Wissenschaftsgeschichte*, vol. 1, pp. 351-376, esp. pp. 354-355).
[2] *K. al-Ḥiyal*, op. cit., pp. 368-371; Engl. transl. D. R. Hill, *The Book of Ingenious Devices*, op. cit., pp. 236-237.

About the purpose of its use the Banū Mūsā say: "People who conduct religious affairs light this lamp. They believe that this provides an eternal lamp in which the fire is not extinguished, in fact, it burns uninterruptedly in the fire pipe that is the case among the Zoroastrians, and it is the case among the Christians in the church. If the lamp-holder (the carrier of the lamp) and the container of oil are set up hidden in the wall so that only the lamp is seen, it makes a better impression on the onlooker."[3]

[3] Translation E. Wiedemann, op. cit., pp. 203-204 (repr., pp. 354-355).

Redrawing by D.R. Hill.

Banū Mūsā, *K. al-Ḥiyal* (MS Berlin, or. quart. 739).

Sketch of a functional model
proposed by D. R. Hill.

Banū Mūsā, *K. al-Ḥiyal* (MS Istanbul,
Topkapı Sarayı, Ahmet III, 3474).

Illustration from Banū Mūsā (MS Topkapı

Redrawing by D.R. Hill.

An astonishing drinking vessel

Our model:
Wooden box 43 × 45 × 100 cm.
Two ornate brass containers, gilded.
Pipes of brass and plastic.
(Inventory No. E 1.09)

The ‹sons of Mūsā› (Banū Mūsā) describe in their *Kitāb al-Ḥiyal*[1] fifteen appliances for drinking vessels and centerpieces which show "in what ingenious manner" they "knew how to solve the most diverse tasks."[2] The eleventh of their appliances served as our model.

The drinking vessel was displayed on social occasions and served for entertainment. The way it worked was based on hydraulic calculations. When wine is poured into it slowly from the top, water will flow out on the left-hand side and wine on the right. When one pours water quickly into it, then wine will flow from the left side and water from the right. We should visualise that in the original the container is covered so that we cannot look inside to see how the apparatus functions.

[1] *Kitāb al-Ḥiyal*, op. cit., pp. 319-323; D. R. Hill, The Book of Ingenious Devices, op. cit., pp. 212-213.
[2] E. Wiedemann, *Über Trinkgefäße und Tafelaufsätze nach al-Ǧazarî und den Benû Mûsà*, in: Der Islam 8/1918/55-93, 268-291, esp. pp. 284-286, 291 (repr. in: *Gesammelte Schriften*, vol. 3, pp. 1517-1579, esp. pp. 1572-1574, 1579).

Automatic vender

for dispensing warm and cold water alternatively

Our model:
Table 84 × 62 cm.
Total height 170 cm.
Brass fittings.
(Inventory No. E 1.28)

Muḥammad, Aḥmad and al-Ḥasan, the three sons of Mūsā b. Šākir, who were active in the first half of the 3rd/9th century in Baghdad as mathematicians, astronomers and physicists,[1] describe, in their book on mechanical devices,[2] an apparatus which serves the purpose of preparing and regulating the flow of water from two different sources or vessels [50] so

[1] v. F. Sezgin, op. cit., vol. 5, pp. 246–252; vol. 6, pp. 147–148.
[2] *K. al-Ḥiyal*, ed. Aḥmad Y. al-Ḥasan, Aleppo 1981, pp. 385–388; Engl. transl. Donald R. Hill, *The Book of Ingenious Devices*, London 1979, pp. 246–247.

that from each one of two pipes the water flows alternately warm or cold at specific intervals, while it flows from the other pipe in the same intervals but in the contrary sequence. By shortening the intervals an effect can be achieved similar to that of the water mixer.
From a container for hot water on the right-hand side and a container for cold water on the left of the apparatus, water flows to a water wheel which is attached horizontally beneath the containers. By means of the rotation of the wheel a tub fixed under it is also set in motion. The tub is divided in the middle into two chambers. At first hot water flows into the right-hand chamber, then after half a rotation the cold water. At the same time cold water flows into the left chamber at the beginning and after half a rotation hot water.
From these chambers the water runs through two large openings into a tub which lies below and which is also divided into two chambers. Because of the rotation of the upper tub the water flows out alternately. After only one fourth of a turn of the upper tub the inflow in the lower one changes. From the lower tub the water is piped to a basin where for one single turn of the water wheel and of the upper tub the inflow from each of the two water pipes changes four times. Hot and cold water flows alternately in short intervals.

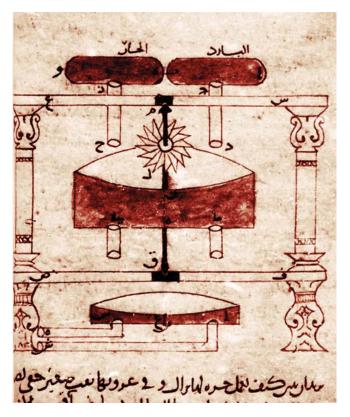
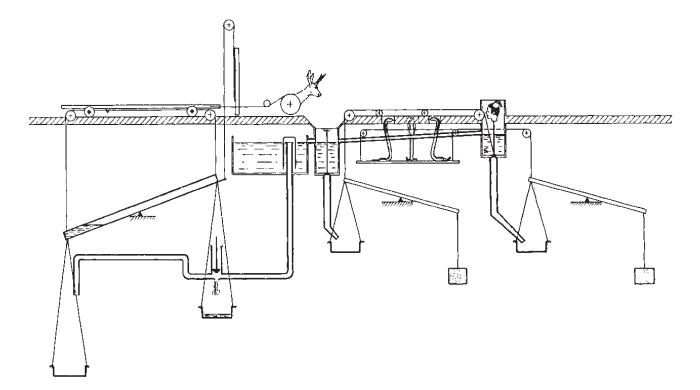
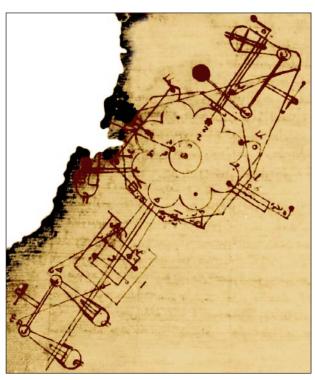



Illustration from Banū Mūsā
(MS Topkapı Sarayı, Ahmet III, 3474).

An automaton for entertainment

Our model:
Width of the wooden box: 110 cm.
Water container and pipes of Perspex.
Bowls of hammered copper.
Figures of cast tin.
(Inventory No. B 1.09)

It is the first of the 31 models described and sketched by a certain Muḥammad or Aḥmad b. Ḫalaf al-Murādī (probably 2nd half of the 5th/11th c. in Andalusia) in his book *Kitāb al-Asrār fī natā'iğ al-afkār*. Together with the following four models of the book, it resembles a water clock, since certain actions appear at fixed intervals, but the function of a precise measurement of time is missing.[1] The model was reconstructed by Eduard Farré (Barcelona),[2] based on the explanations and sketches by J. Vernet, R. Casals and M.V. Villuendas.[3] The use of mercury in this automaton is noteworthy; this establishes a connection between this device and the Alphonsine mercury clock (see above, III, 110 ff.).[4] On the other hand it is striking that typical elements of Arabic technology are absent, such as "conical valves, delay systems, feedback controls, or use of small variations in atmospheric pressure."[5]

[1] Donald R. Hill, *Arabic Water-Clocks*, op. cit. p. 37.
[2] J. Vernet and J. Samsó (eds.), *El Legado Científico Andalusí,* pp. 304–309.
[3] *El capítulo primero del "Kitāb al-asrār fī natā'iğ al-afkār"*, in: Awrāq (Madrid) 5–6/1982–83/7–18.
[4] D.R. Hill, *Arabic Water-Clocks*, p. 39.
[5] Ibid., p. 39.

The complicated movement triggers a mechanism after about half an hour (in our model the time is reduced to five minutes). Then the two doors open and two dancing girls appear. At the same time four he-goats lower their heads for drinking. Thereupon a snake-charmer emerges out of a well and the dancing girls move back into the house and the doors close at the same time. The goats also lift their heads once again. Then three snakes rise in front of the well; after some time the snake-charmer disappears first and then the snakes.

On the book by al-Murādī: D. R. Hill, *A Treatise on Machines by Ibn Muʿādh Abū ʿAbd Allāh al-Jayyānī*, in: Journal for the History of Arabic Science (Aleppo) 1/1977/33-46; A. I. Sabra, *A Note on Codex Biblioteca Medicea-Laurenziana Or. 152*, ibid. pp. 276-283; M. V. Villuendas, *A Further Note on a Mechanical Treatise Contained in Codex Medicea Laurenziana Or. 152*, in: Journal for the History of Arabic Science (Aleppo) 2/1978/395-396; J. Vernet, *Un texto árabe de la corte de Alfonso X el Sabio. Un tratado de autómatas*, in: Al-Andalus (Madrid, Granada) 43/1978/405-421; D. R. Hill, *Arabic Water-Clocks*, op. cit. pp. 36-46; R. Casals, *Consideraciones sobre algunos mecanismos árabes*, in: Al-Qantara (Madrid) 3/1982/333-345; D. R. Hill, *Tecnología andalusí*, in: El Legado Científico Andalusí, pp. 157 ff., esp. pp. 163-168, 304-309; J. Samsó, *Las ciencias de los antiguos en al-Andalus*, Madrid 1992, pp. 250-257; J. Casulleras, *El último capítulo del* Kitāb al-asrār fī natāʾiŷ al-afkār, in: *From Baghdad to Barcelona*. Studies in the Islamic Exact Sciences in Honour of Prof. Juan Vernet, Barcelona 1996, vol. 2, pp. 613-653.

Drawing from al-Murādī, *Kitāb al-Asrār*
(MS Florence, Biblioteca Medicea Laurenziana, orient. 152).

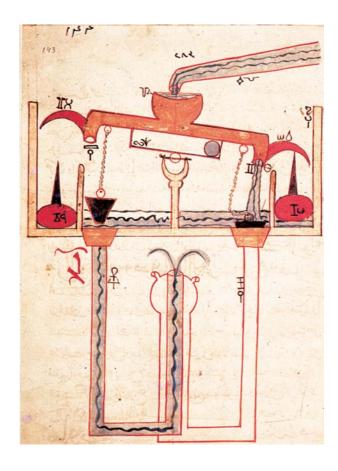
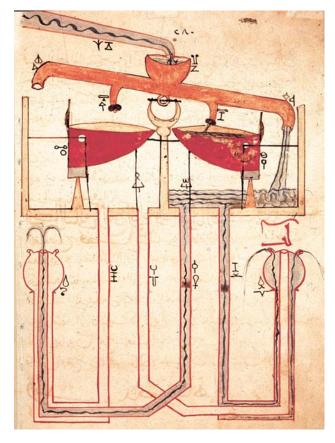
Fountain
with varying appearance

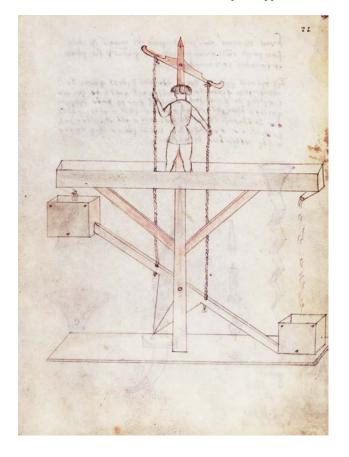
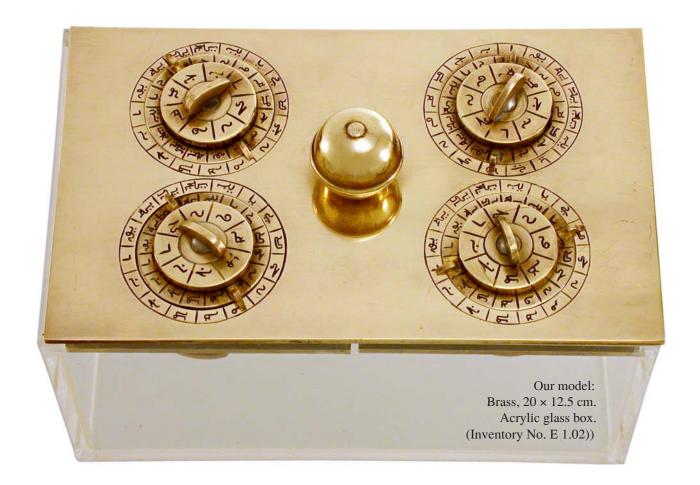
Our model:
Total height: 110 cm.
Brass frame around Perspex.
Ornate bowl and lid,
also see-saw of gilt brass.
Copper float and pipes.
(Inventory No. B 1.07)

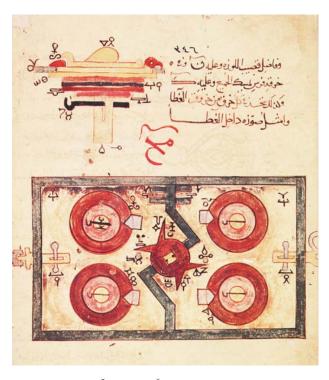
I.
This is one of the two devices originally described in the 3rd/9th century by the Banū Mūsā which Ibn ar-Razzāz al-Ǧazarī (ca. 600/1200) found deficient and replaced with his own constructions.

The water, which was originally supplied from outside, is piped back into the model from the lower water container and flows in the upper part over a see-saw into the right-hand one of the two chambers. When this is completely full, the see-saw, regulated by a float, swings round so that the left chamber is filled. In this time, which is precisely calculated, the water of the right-hand chamber flows out of a pipe and rises as a single jet out of the central nozzle of the lower basin. Then the see-saw turns around, so that the water of the left chamber empties through the second pipe and rises as five jets out of the lower nozzle ring. The interval was originally half an hour, in our model it is shortened to three minutes.

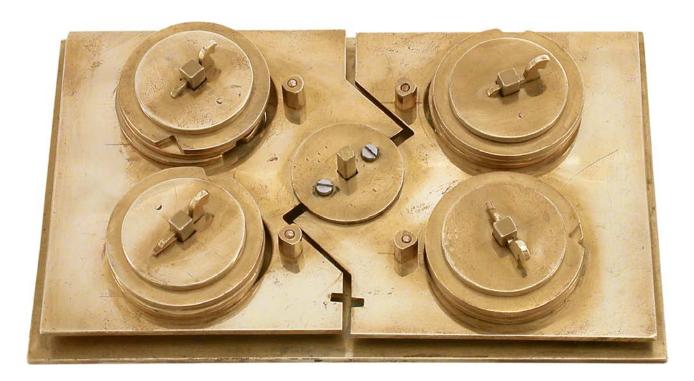
Literature: al-Ǧazarī, *al-Ǧāmiʿ*, facsimile, Ankara 1990, pp. 276-277; E. Wiedemann, *Die Konstruktion von Springbrunnen durch muslimische Gelehrte*. II. *Anordnungen von al Ǧazarî für Springbrunnen, die ihre Gestalt wechseln*, in: Festschrift der Wetterauischen Gesellschaft für die gesamte Naturkunde, Hanau 1908, pp. 29-43, esp. 36 ff. (repr. in: E. Wiedemann, *Gesammelte Schriften*, vol. I, pp. 241-255, esp. p. 248 ff.; D. R. Hill, *The Book of Knowledge of Ingenious Mechanical Devices*, p. 158 ff.

2.
The second
of the fountains
constructed and described by al-Ǧazarī

Our model:
Total height: 130 cm.
Brass frame around Perspex.
Copper tub and shovel.
Ornate lid and pipes gilded.
(Inventory No. B 1.08)

Here also the water flows over a see-saw first into the right-hand chamber. At the same time a scoop is filled with water until it is so heavy that it tips over, thereby tilting the see-saw and enabling the chamber to be drained. While the left chamber is filling, the water bubbles out as two jets: a mushroom of water forms on the left side, a jet on the right-hand side. After a specific time the water of the left chamber empties. Now the mushroom of water is to be seen on the right-hand side, the jet on the left. Here too the interval was originally half an hour; it is shortened in our model to three minutes.

Literature: al-Ǧazarī, *al-Ǧāmiʿ baina l-ʿilm wa-l-ʿamal*, facs. ed., Ankara 1990, pp. 278-279; E. Wiedemann, *Anordnungen von al Gazarî*, op. cit., p. 36 ff. (repr., p. 248 ff); D. R. Hill, *The Book of Knowledge*, op. cit., p. 158 ff.

Illustrations from al-Ǧazarī, op. cit., pp. 280, 283.

On folio 22r of his *Bellicorum instrumentorum liber*, Giovanni Fontana (1st half of 15th cent.)[1] draws the main features of a fountain which betrays his knowledge of an Arab model (see fig. on the right).

[1] Eugenio Battisti and Giuseppa Saccaro Battisti, *Le macchine cifrate di Giovanni Fontana*, Milan 1984, p. 118.

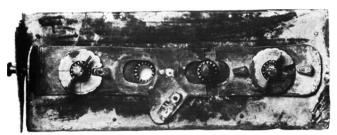
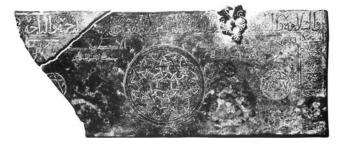
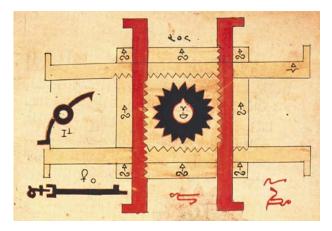
Our model:
Brass, 20 × 12.5 cm.
Acrylic glass box.
(Inventory No. E 1.02))

A combination lock

In the last chapter of his book Ibn ar-Razzāz al-Ǧazarī (ca. 600/1200) deals with a number of mechanical devices, among them a letter-lock, a ‹lock with twelve letters which serves to lock a box› (*qufl yuqfalu ʿalā ṣandūq bi-ḥurūf iṯnā ʿašar min ḥurūf al-muʿǧam*)[1].

Drawing from al-Ǧazarī, *al-Ǧāmiʿ baina l-ʿilm wa-l-ʿamal,* op. cit., p. 346.

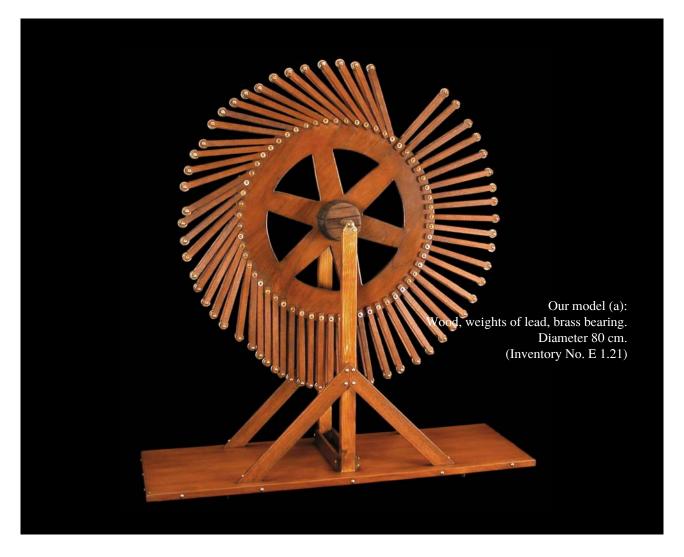
[1] *al-Ǧāmiʿ baina l-ʿilm wa-l-ʿamal*, facs. ed. Ankara 1990, pp. 340–348; German transl. E. Wiedemann, *Über eine Palasttüre und Schlösser nach al-Ǧazarī*, in: Der Islam 11/1921/213–251, esp. pp. 232–244 (repr. in: *Gesammelte Schriften*, vol. 3, pp. 1670–1708, esp. pp. 1689–1701), Engl. transl., D. R. Hill, *The Book of Knowledge of Ingenious Mechanical Devices*, op. cit., pp. 199–201

The lid consists of two plates which are connected with four combination locks and a turning knob. The cover plate serves as a clamping device. The plate lying underneath consists of two halves which can be pushed apart with the knob. However, this is only possible when the locks are adjusted to a certain combination. Then the rings in the locks set free a groove into which the security pegs, which are affixed to the lower plate, can slide. When the combination lock is placed upon a box for which it is intended, the lower plate can slide into the two recesses by means of the knob. At the same time a cylinder is pushed into a guideway attached on the side so that the lower plate cannot be pushed together any more. By altering the combination the cylinder is secured. The twelve-digit combination of Arabic characters, each of which corresponds to a numerical value, can be easily changed when the lid is opened.

Page with the description and illustration of the number lock from al-Ǧazarī, *al-Ǧāmiʿ baina l-ʿilm wa-l-ʿamal*, facs. ed., Frankfurt 2002, p. 523.

Small ivory casket preserved from the period of al-Ǧazarī (ca. 600/1200) with a combination lock of Arabic characters (191 × 201 × 375 mm). Metal mounts and lock of gilded copper alloy. Maastricht, Stichting Schatkamer Sint Servaas (Belgium).

Two more caskets with combination locks from the 7th/13th cent.; on the left: Khalili Collection, London, op. cit., vol. 12, No. 344. Above: part of a small box by Muḥammad b. Ḥāmid al-Iṣfahānī, dated 597/1200, Copenhagen, David Collection, ref. No. 1/1984.

Door lock

with four bolts

Drawing from al-Ǧazarī, op. cit., p. 352.

In the last chapter of his *Ǧāmiʿ baina l-ʿilm wa-l-ʿamal* Ibn ar-Razzāz al-Ǧazarī (ca. 600/1200) describes a door lock with four bolts: "There are four bolts made of wood or iron, on the back of a door; they are on four sides, but placed in different directions. They are pushed forward and opened by a key. One bolt opens to the right, one to the left, one upwards and another downwards. There is no space in the four bolts which a malicious person (*ṭāriḥ*) can infiltrate. When the key is taken out of the hole in which it fits in order to open and to push the bolts forward, nobody is in a position to achieve what is the purpose of the bolting and to push the bolts with the hand upwards or downwards or to the right or to the left; then they cannot be moved, either for bolting or for opening. The only thing with which one can move them is the key."[1] After this description of the function of the key, al-Ǧazarī gives a detailed description of the mechanism and its component parts.

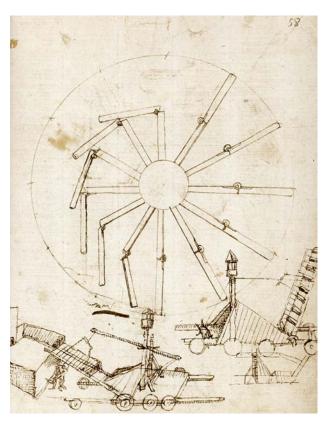
Our model:
Wood, brass and Perspex.
Measurements: 51 × 43 × 58 cm.
(Inventory No. E 1.10))

[1] al-Ǧazarī, *al-Ǧāmiʿ bain al-ʿilm wa-l-ʿamal*, facs. ed., Frankfurt 2002, pp. 532–537; Ankara 1990, pp. 348-352; German transl. E. Wiedemann, *Über eine Palasttüre und Schlösser nach al-Ǧazarī*, in: Der Islam 11/1921/213-251, esp. pp. 244-250 (repr. in: *Gesammelte Schriften*, vol. 3, pp. 1670-1708, esp. pp. 1701-1707), Engl. transl. D. R. Hill, *The Book of Knowledge of Ingenious Mechanical Devices*, op. cit., pp. 202-203.

Our model (a):
Wood, weights of lead, brass bearing.
Diameter 80 cm.
(Inventory No. E 1.21)

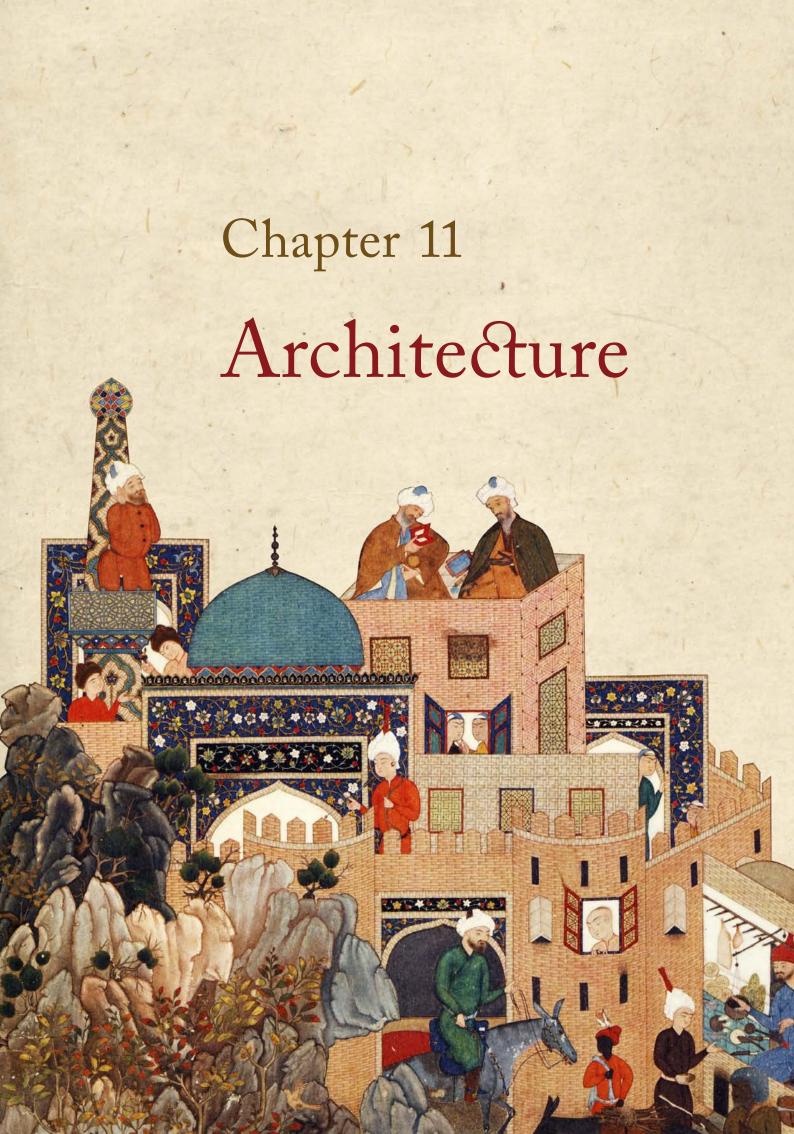
Perpetuum Mobile

The depiction of various forms of perpetua mobilia in the three extant manuscripts of the anonymous Arabic anthology of technical content (probably from the 6th/12 cent., see above, p. 35)[1] creates the impression that the idea of something ‹continuously moving›, of a machine that turns without any external supply of energy, was fairly widespread, even at that time, indeed, it was part of a certain tradition. How far this tradition goes back to Greek or Byzantine sources is not known at present. The same idea with which Europeans up to the 19th century occupied themselves so passionately[2] appears in Europe shortly before the middle of the 13th century in the work of the French engineer Villard de Honnecourt[3] and then in the work of his younger compatriot Peter Peregrinus.[4]

[1] According to MS Gotha 1348, fol. 105b; Leiden, Warn. 499 (= or. 499), fol. 80 a. Cf. H. Schmeller, *Beiträge zur Geschichte der Technik in der Antike und bei den Arabern*, Erlangen 1922, p. 21 (repr., op. cit., p. 221).

[2] v. F. M. Feldhaus, *Ruhmesblätter der Technik*, Leipzig 1910, pp. 217-230.
[3] Sarton, *Introduction* II, op. cit., p. 1033.
[4] v. E. Grant, in: Dictionary of Scientific Biography X, 1974, col. 536[b].

Our model (b):
Wood and brass.
Diameter 26 cm.
(Inventory No. E 1.22)

Drawing from Mariano Taccola's notebook (1st half of 15th cent.).[6] At the bottom of the page there are sketches of war machines. The perpetuum mobile is, due to its striking similarity with the one depicted in our model, another piece of documentary evidence of the decisive importance of older Islamic sources for the protagonists of the ‹Renaissance›.

Later the interest in perpetua mobilia grew to such an extent that the Académie Française decided in 1775 not to examine any proposals for the solution of this problem any more.
As far as we know, the astronomer and physicist Taqīyaddīn b. Maʿrūf was the first scholar in the Islamic world to point out, in the middle of the 10th/16th cent., the absurdity of the perpetuum mobile.[5]

Our Arabic anthology describes seven types of perpetua mobilia, four of which were meant to be set in motion by mercury.
Although the models presented here—whose friction loss could, of course, have been reduced further—do not by definition function, they are of interest in so far as they document an advanced knowledge of the principle of the lever and the calculation of the momentum.

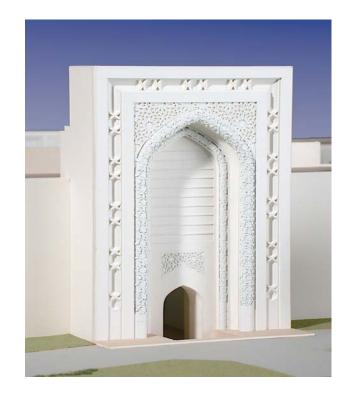
v. Sevim Tekeli, *16'ıncı asırda Osmanlılarda saat*, Ankara 1966, p. 218.

[6] *De ingeneis,* vol. 2, facsimile ed., Wiesbaden 1984, fol. 58a.

Chapter 11

Architecture

In lieu of an introduction

The author of these lines does not feel sufficiently competent to write an introduction to the material presented here. An introduction, moreover, is not necessary in view of the small number of our models compared to the numerous extant architectural monuments of the Arab-Islamic world. Our selection concentrates on a few functional public buildings which were exemplary for their times. These were always endowed by prominent personalities, mostly the rulers themselves; therefore they represent not only the advanced architecture and engineering in each case, but also demonstrate the enormous cultural importance which was attached, not only to mosques, but primarily to hospitals and academies of higher learning.

The Mustanṣirīya University in Baġdād

Our model:
Wood and plastic.
Scale ca. 1:50.
Measurement of the base plate:
100 × 60 cm.
Steel frame and transparent hood.
(Inventory No. F 05)

This great university was founded in 625/1227 on the banks of the Tigris in Baghdad by the penultimate Abbasid Caliph al-Mustanṣir billāh. It is probably the oldest Arab-Islamic university where, besides the syllabus of the four orthodox law schools, medicine and mathematical sciences were also taught.[1] The maintenance of the University was secured by an endowment founded by the Caliph. The number of lecturers and other staff was ca. 400. The University had a large and important library which was plundered after the conquest of Baghdad by the Mongols. The Caliph often visited the University and «heard the lectures and the disputations of the scholars from a special place. Every now and then he held official receptions for state guests there.»

Yaḥyā b. Maḥmūd al-Wāsiṭī: illustration to the Maqāmāt by al-Ḥarīrī, *Lecture in a library at Basra* (634/1237), Bibl. Nat. Paris, MS arabe 5847, fol. 5.

[1] For the references to the sources, see Nāǧī Maʿrūf, *Tārīḫ ʿulamāʾ al-Mustanṣirīya*, 3rd ed. Cairo, n.d., vol. 1, pp. 25, 48.

General view of our model,
seen from the East.

0 10 20 30 M

مخطط الطابق الثاني من المدرسة المستنصرية

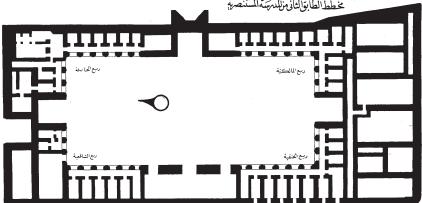



Fig. 1: Plan of the second storey of the Madrasa al-Mustanṣirīya, after the building survey by the Department of Antiquities of Iraq.

مخطط الطابق الاول من المدرسة المستنصرية

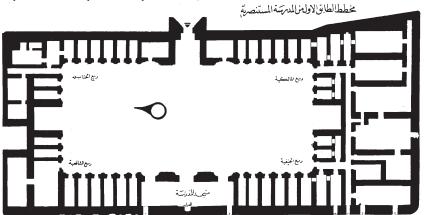
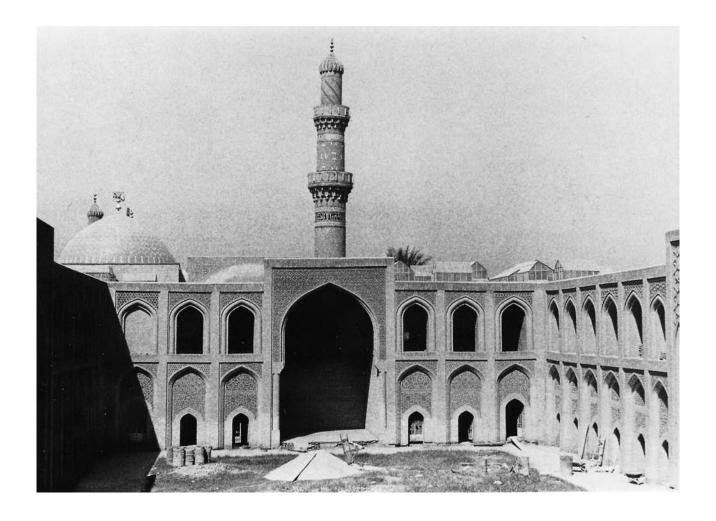



Fig. 2: Ground plan of the first storey of the Madrasa al-Mustanṣirīya, after the building survey by the Department of Antiquities of Iraq.

Plan from Hansjörg Schmid,
Die Madrasa des Kalifen al-Mustansir in Baghdad. Eine baugeschichtliche Untersuchung der ersten universalen Rechtshochschule des Islam. Mit einer Abhandlung über den sogenannten Palast in der Zitadelle in Baghdad,
Mainz 1980.

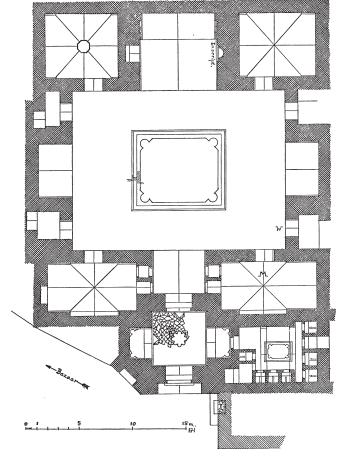
«The building survived the destruction of the capital and the downfall of the Abbasid dynasty at the conquest by the Mongols in 1258, ...» A decade later the University started functioning once again. It seems to have been much neglected in recent centuries. After its restoration between 1945 and 1962 the building is now part of the Museum of Islamic Culture and Art.[2] Our model was built on the basis of the commendable work by Hansjörg Schmid.

Photo of the façade and a view of the courtyard from Hansjörg Schmid, op. cit.

[2] Hansjörg Schmid, *Die Madrasa des Kalifen al-Mustansir in Baghdad*, op. cit., p. 1.

Our model:
Wood and plastic.
Scale ca. 1:50.
Measurement of the base plate: 100 × 70 cm.
Steel frame and transparent hood.
(Inventory No. F 07)

The Nūraddīn hospital
in Damascus

This hospital, known by the name of al-Bīmāristān an-Nūrī, was founded in 549/1154, immediately after the liberation of the city, by Amīr Nūraddīn Maḥmūd b. Zangī, who was of Turkish descent and the predecessor of the Ayyubid Ṣalāḥaddīn (Saladin).[1] It was one the most famous hospitals in the Islamic world and functioned up to the 13th/19th century. Besides the Great Mosque and the Citadel, it is counted among the most important monuments of the Islamic period in Damascus. On the manner of functioning and the organization of the hospital, the Andalusian scholar Ibn Ǧubair (d. 614/1217) wrote the following account in his travelogue on the occasion of his visit to Damascus in 580/1184:[2] «In this place (Damascus) there are about twenty schools and two hospitals, an old one and a new one. The new one is more frequented and is larger. Its [69] daily upkeep costs about fifteen dinars. There are employees who look after the registration of the names of the patients and the necessary

[1] see E. Herzfeld, *Damascus: Studies in Architecture*, in: Ars Islamica (Ann Arbor) 9/1942/1-53, esp. p. 4.

[2] *The Travels of Ibn Jubayr*, ed. W. Wright, 2nd ed., rev. M. J. de Goeje, Leiden 1907, p. 283; E. Herzfeld, *Damascus: Studies*, op. cit., p. 5; A. Issa Bey, *Histoire des Bimaristans (hôpitaux) à l'époque islamique*, Cairo 1928, p. 98.

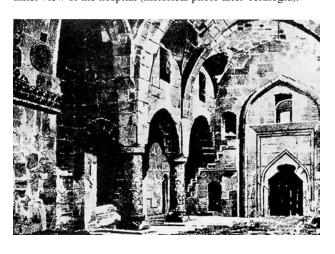
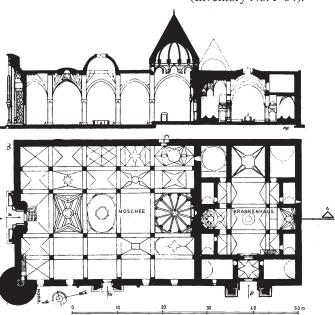
expenditure on medicines, food etc. The doctors come every day early in the morning, examine the patients and prescribe the medical care with the requisite medicines and food, taking into consideration the condition of each patient … There is also treatment for mental patients …»

Ground plan of the hospital after E. Herzfeld.

«In the ground plan of this oldest hospital preserved until now, four īwāns (vaulted halls) are grouped symmetrically around an inner courtyard and together they form a cross. There is a water basin at the centre of the inner courtyard.» «Through the muqarnaṣ portal situated in a flat niche you enter into a square anteroom with a muqarnas vault. From this room the visitor goes into the western īwān. The eastern īwān facing it was, according to an inscription, the examination or consulting room. The four vaulted rooms in the corners, with no windows to the outside, were wards.»[3]

[3] Arslan Terzioğlu, *Mittelalterliche islamische Krankenhäuser unter Berücksichtigung der Frage nach den ältesten psychiatrischen Anstalten*, PhD diss., Berlin 1968, p. 80; cf. J. Sauvaget, *Les monuments historiques de Damas*, Beirut 1932, pp. 49-53.

The hospital
of Princess Tūrān

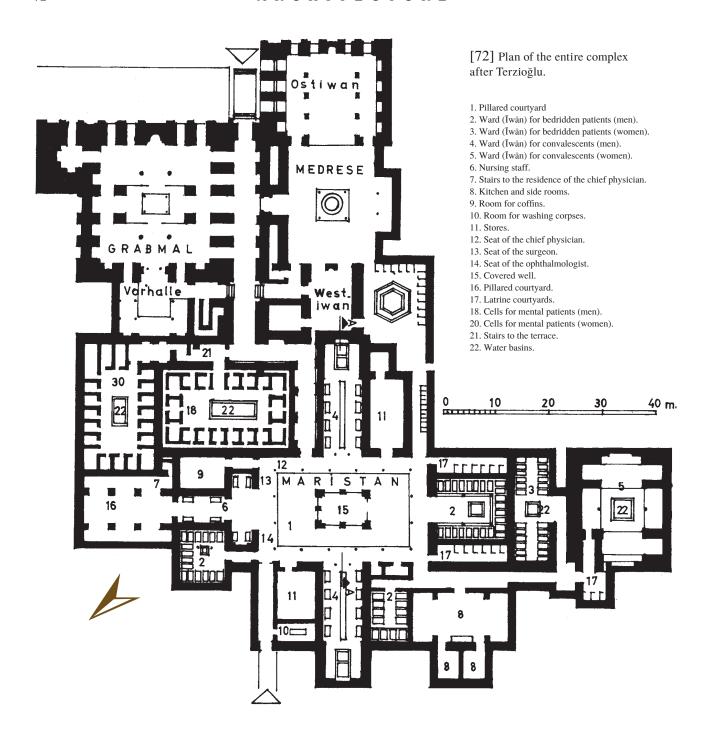
Our model:
Wood and plastic. Scale ca. 1:50.
Steel frame and transparent hood
(Inventory No. F 04).

The oldest completely preserved hospital of Anatolia was erected by Aḥmad Šāh of the local dynasty of Mengüček in 625/1228 on the instructions of Princess Tūrān, a daughter of Faḫraddīn Bahrām Šāh and wife of Aḥmad Šāh. It is situated in Divriği (south-east of Sivas) next to the mosque erected by Aḥmad Šāh. The hospital part covers an area of 32 × 24 metres; the area of the total complex, together with the mosque, amounts to 32 × 64 metres.[1]

Ground plan and longitudinal section of the entire complex (after Terzioğlu)

Inner view of the hospital (historical photo after Terzioğlu).

[1] Arslan Terzioğlu, *Mittelalterliche islamische Krankenhäuser*, pp. 121–125.

Our model:
(of the preserved portion):
Wood and plastic.
Base plate 94 × 119 cm.
(Inventory No. F 08)

The Qalāwūn hospital
in Cairo

The most famous and most important hospitals in the Arab-Islamic world undoubtedly include the al-Māristān al-kabīr al-Manṣūrī in Cairo, which is known in modern publications as Qalāwūn Hospital. Its founder was the Mamluk Sultan al-Malik al-Manṣūr Saifaddīn Qalāwūn (ruled 678/1279-689/1290). He was inspired to build the hospital by his visit to the Bīmāristān an-Nūrī in Damascus in 675/1276. Five years after his accession to power in Cairo, i.e. in 683/1284, he ordered the work to begin.[1] A madrasa was attached to the

[1] On the foundation and the progress of the construction, the historian al-Maqrīzī (766/1364- 845/1442) informs us at length in his book *al-Ḫiṭaṭ wa-l-āṯār* (Būlāq 1270, vol. 2, pp. 406-408). His report, of high documentary value for the history of hospitals, is reproduced here in parts, after the translation by F. Wüstenfeld (*Macrizi's Beschreibung der Hospitäler in al-Câhira*, in: Janus [Breslau] 1/1846/28-39, esp. pp. 32-38, reprint in: Islamic Medicine, vol. 93, pp. 126-145, esp. pp. 138 ff.) with certain modifications:
«The reasons for the construction were the following: when al-Malik al-Manṣūr was still an amīr and was fighting against the Franks during the reign of Malik aẓ-Ẓāhir Baibars in 675/1276, he had a violent attack of colic in Damascus and the physicians healed him with medicines brought from the hospital of … Nūraddīn. After his recovery, he rode up to the hospital, admired it and vowed that he would build a hospital if God granted him the throne. Later when he became Sultan he set out to fulfil the vow, and his choice fell on the Quṭbīya building. He gave the ‹emerald castle› to the owners in exchange and entrusted Amīr ʿAlamaddīn Sanǧar aš-Šuǧāʿī with the responsibility for the construction. He left the central court as it was and equipped it as a hospital; it consisted of four wards, in each ward there was a fountain, and in the middle of the courtyard there was a container into which the water of the fountains flowed … When the building was completed

[72] Plan of the entire complex after Terzioğlu.

1. Pillared courtyard
2. Ward (Īwān) for bedridden patients (men).
3. Ward (Īwān) for bedridden patients (women).
4. Ward (Īwān) for convalescents (men).
5. Ward (Īwān) for convalescents (women).
6. Nursing staff.
7. Stairs to the residence of the chief physician.
8. Kitchen and side rooms.
9. Room for coffins.
10. Room for washing corpses.
11. Stores.
12. Seat of the chief physician.
13. Seat of the surgeon.
14. Seat of the ophthalmologist.
15. Covered well.
16. Pillared courtyard.
17. Latrine courtyards.
18. Cells for mental patients (men).
20. Cells for mental patients (women).
21. Stairs to the terrace.
22. Water basins.

al-Malik al-Manṣūr endowed for it so much landed property in Egypt and other countries that every year an income of nearly one million dirhams was received, and he determined the places where the money for the hospital, the house of prayer, the academy and the school for orphans should be paid. After this he ordered a cup of wine to be brought from the hospital, drank from it and proclaimed: This I have endowed for my equals and for those lesser than I am, I have designated it as an endowment for the king and for the servant, for the soldier and for the amir, for the big and for the small, for the free man and for the slave, for men and women. He determined for it all the medicines, the physicians and all the rest which anyone could be in need of during any illness. The Sultan employed male and female bed-makers for the service of the patients and he determined their salaries; he erected the beds for patients and provided them with all kinds of blankets which were necessary in any disease. Each class of patients was given a special room. He assigned the four wards of the hospital for those suffering from fever and similar illnesses, one ward for those suffering from eye diseases, one for the wounded, one for those who suffered from diarrhoea and one for women; he divided a room for those who are on their way to recovery into two parts, one for men and the other one for women. Water is piped to all these areas. One special room was for cooking the food, medicines

Details of our model, left: façade from the north-west; right: reconstructed inner hall (No. 4 in the plan above)..

hospital [73], which Wüstenfeld correctly understands as an academy. It is not certain whether medical lectures were held there or in special rooms of the hospital. Probably the staff included the physician and versatile scholar ʿAlī b. Abi l-Ḥazm Ibn an-Nafīs (d. 687/1288), the discoverer of pulmonary circulation,[2] who donated his house and his library to the hospital.[3]
The hospital was still in good condition in the 17th century and seems to have fallen into disrepair only in the 18th century. Today the supporting walls are still standing for the most part. At the beginning of the 20th century a new hospital with the same name was built as an extension of the old building.[4] The Egyptian government also plans to restore the old building once again.

Pascal Coste, a French engineer who was commissioned to build factories by the Egyptian government in1818-1825, left behind some valuable drawings of the views and a sketch of the ground plan of the hospital.[5]
The three endowment documents of the hospital from the years 684/1285, 685/1286 and 686/1287 were rediscovered in 1913 in Cairo and are now with the Ministry of Endowments there. The excerpts translated into French by the historian of medicine Ahmad Issa Bey[6] testify to the high standard of the hospital organization in the Arab-Islamic world in the 7th/13th century.

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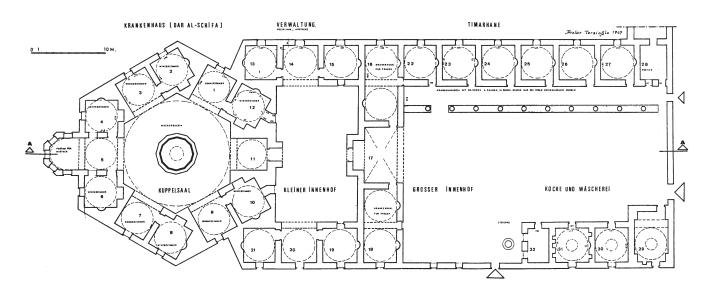
and syrups, another for mixing the confectionery, balsams, eye ointments etc. The supplies were stored at various places, in one room there were only syrups and medicines, in one room the chief physician had his seat to hold medical lectures. The number of patients was not restricted, with any needy or poor person who came there being admitted. Likewise the time a patient spent there was not fixed, and even those who were lying ill at home were supplied from there with all that they needed.»
[2] On some relevant articles, see vol. 79 of the series Islamic Medicine (Frankfurt).

[3] Ibn Faḍlallāh al-ʿUmarī, *Masālik al-abṣār fī mamālik al-amṣār*, facs. ed., Frankfurt 1988, vol. 9, p. 350
[4] Arslan Terzioğlu, *Mittelalterliche islamische Krankenhäuser*, op. cit., pp. 88-106.
[5] *Architecture arabe ou monuments du Kaire, mesurés et dessinés de 1818 à 1825*, Paris 1839 (repr. Böblingen 1975), pp. 74-81.
[6] *Histoire des bimaristans (hôpitaux) à l'époque islamique*, Cairo 1928, pp. 61–72.

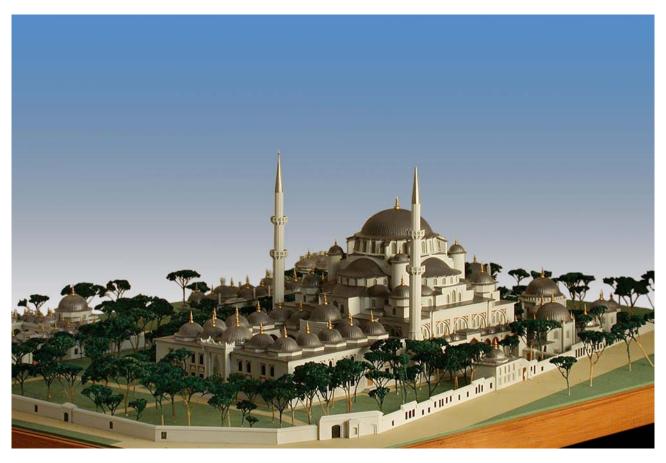
The hospital
of sultan Bāyezīd II in Edirne

Our model:
Wood and plastic. Scale 1:50.
Measurement of the base plate: 103 × 55 cm.
Steel frame and transparent hood.
(Inventory No. F 06))

The hospital was founded in 889/1484 together with an academy (*madrasa*), a mosque and a canteen for the poor (*ʿimārat*) on the banks of the river Tunca in Edirne. «Behind the mosque on the banks of the Tunca Sultan Bayezid II arranged for a harbour to be built so that he could go by ship from this building complex to his castle in Edirne.»[1]
According to Terzioğlu the hospital consists of three parts: The «hospital proper (Dār aš-šifāʾ) with a large central dome and 12 small ones». Next to it, a «part of the building, grouped around a small inner courtyard, which primarily serves administrative purposes». And «adjoining the madrasa, a part of the building with a large inner courtyard, kitchen and laundry.»
«The hospital proper is a large hexagonal building, about 30 metres in diameter, with six rooms as closed rooms for patients and with five recesses in the form of īwāns. The rooms for the patients and the recesses surround a middle hall, which is vaulted over by a dome. This made it possible to look after several patients with limited nursing staff … Here the architect Hayreddin primarily created a functional building. While the adjoining academy exhibits once again the old madrasa type, the peculiar form of the hospital testifies to the fact that the architect broke new ground, while taking the functional aspect into account.
[75] Thanks to an endowment document of 52 pages from 893/1488, we know in detail about the nature and manner of the work at the hospital and about its organization and finances.[2] A valuable description of the hospital is given by the famous traveller Evliyā Çelebī (11th/17th c.). It was translated

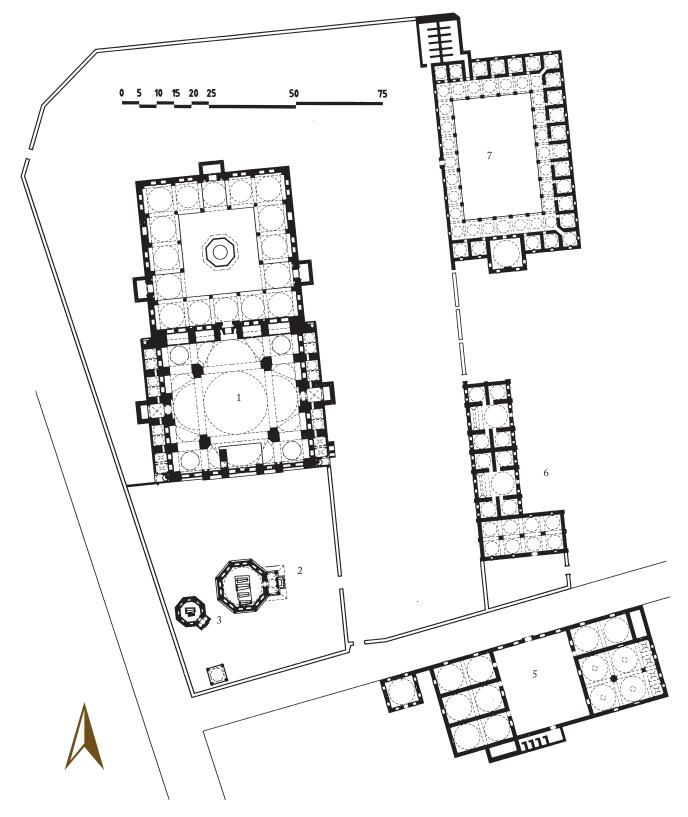
[1] A. Terzioğlu, *Mittelalterliche islamische Krankenhäuser*, op. cit., p. 190.

[2] For the literature on the document, see A. Terzioğlu, op. cit., pp. 190-191.

into German in 1912 by Georg Jacob.[3] From this we will cite here, with some slight modifications, his observations on the music therapy of mental patients: «I have seen a remarkable thing: His late majesty, Bajezid II … has employed 10 musicians for the cure of patients in the endowment document, for the recovery of those suffering from pain, for strengthening the mind of the insane and for repelling the gall; 3 of them are singers; of the remaining, one player each of the reed flute (*nāyzen*), the fiddle (*kemānī*), the panpipes (*mūsīqārī*), the dulcimer (*ṣantūrī*), the harp (*čengī*), the harp psalterion (? *čengī-ṣantūrī*) and of the lute (*ʿūdī*). They come three times a week and play for the patients and the insane. By the grace of the Almighty many of them feel relief. In fact, according to the science of music, the makams *nevā*, *rāst*, *dügāh*, *segāh*, *čārgāh* and *sūzināk* are intended for these [patients and insane]. But when the makams *zengūle* and *būselik* [are played] and concluded with the makam *rāst*, then it is as if they have brought new life.
In all instruments and modes there is food for the soul.»

The hospital was functioning until shortly before the beginning of the First World War, with a brief interruption between 1876 and 1894 because of the Russo-Turkish war. At the beginning of the second half of the 20th century it underwent a radical renovation.

Part of the model of the domed hall with rooms 1-13 and 21, 31 × 31 cm.

Ground plan of the hospital of Bāyezīd II (after Terzioğlu).

[3] *Quellenbeiträge zur Geschichte islamischer Bauwerke*, in: Der Islam 3/1912/358-368, esp. pp. 365-368; cf. W. F. Kümmel, *Musik und Medizin*, Freiburg and Munich 1977, pp. 258-259.

The
Şehzāde Mosque
in Istanbul

Our model:
Wood and plastic.
Domes of cast lead.
Scale 1:50.
(Inventory No. F 09)

Our model conveys the simple lines of the external form of a mosque complex in which many historians of architecture see the beginning of the period of the grand mosques of Istanbul. As to the question of its emergence, scholars distinguish between two important stages of development of Ottoman architecture: the beginnings from ca. 700/1300 in Anatolia and in Edirne up to the conquest of Byzantium in 857/1453, and the subsequent ingenious and monumental style, which was inspired by the direct acquaintance with Hagia Sophia and other ancient monuments of the new capital.[1] The Şehzāde Mosque is the first of the three grand mosques built by Miʿmār Sinān (b. 895/1490, d. 996/1588), the greatest architect of the Ottomans. The mosque complex was erected by Qānūnī Süleyman (‹the Magnificent›) in memory of his first son Prince Meḥmed, who died in 950/1543. The year when the construction began is in dispute; but the building was completed in 955/1548. A higher officer, Sinān by name, who had made a name for himself as a pioneering engineer [78] and had already built some smaller mosques, was entrusted with the planning and the execution. He himself remarked later

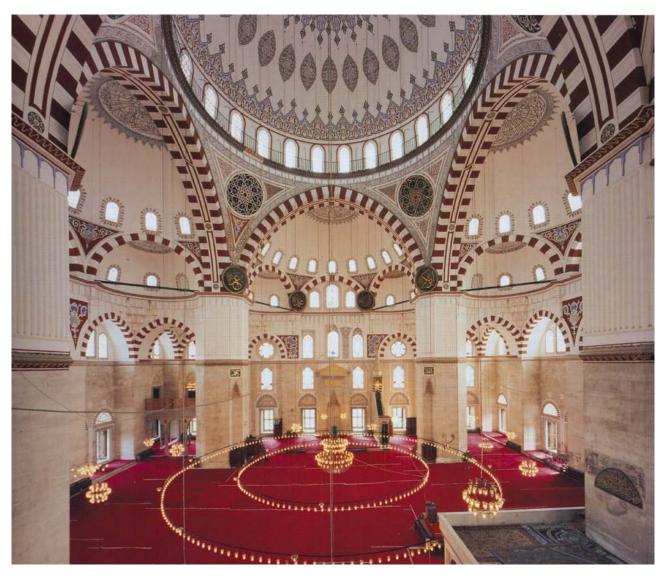
[1] Doğan Kuban, *Sinan'in sanatı ve Selimiye*, Istanbul 1997, pp. 57 ff.

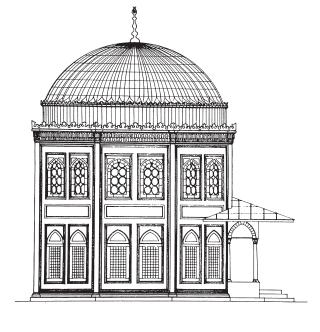
[1] Doğan Kuban, *Sinan'ın sanatı ve Selimiye*, Istanbul 1997, pp. 57 ff.

Plan of the parts of the Şehzāde Complex which go back to Sinān (after Kuban)

1: Mosque
2: Mausoleum (*türbe*) of Şehzāde (Crown Prince) Meḥmed
3: Mausoleum (*türbe*) of (Chancellor) Rüstem Paša
4: Primary school (*mekteb*)
5: Canteen for the poor (*imaret*)
6: Caravanserai
7: Academy (*medrese*)

Figs.: epitaphs of the mausoleum (türbe) of Şehzāde Meḥmed and that of Rüstem Paša in the Şehzāde complex.

that this «first imperial mosque on a truly monumental scale» was his «apprentice work».[2] «Sinān, who from the very first envisaged a centralized ground plan, adopted the expedient of extending the space under the dome not by two but by four separate half domes. This was the most obvious and logical way of combining the centralization with the enlargement of space; but this also contained the danger of producing too much uniformity and symmetry, which could easily become tiresome. Furthermore, the four great pillars that support the dome look stranded and isolated in the middle of the vast space; thus their inevitably large size becomes accentuated in an almost excessive manner. Sinan appears to have realized these aesthetic shortcomings after the construction was over, for he never repeated them again. On the other hand, the whole complex gives the impression as if a systematic attempt was made here to explore the entire range of possibilities of laying the ground plan. This leads to the assumption that perhaps the idea here was to create something like a prototype model of a mosque from which in gradual stages a wide variety of more lively ground plans could be derived.» [3]

The mosque has a total of 183 windows, «which let in uniform brightness to the homogeneous space in all parts. The windows still have their old glass panes with delicate lattice windows and some parts of colour painting.»[4] The length of the main dome measures 19 metres, its vertex is 37 metres high.[5] Besides the mosque, the whole complex includes an academy (medrese), a children's school, a canteen for the poor and a caravanserai. They are located outside the walls of the courtyard. In the courtyard of the mosque there is the mausoleum of Prince Meḥmed.

[2] John Freely, Hilary Sumner-Boyd, *Istanbul*, German transl. Wolf-Dieter Bach, Munich 1975, p. 237.
[3] ibid., p. 238.

[4] Cornelius Gurlitt, *Die Baukunst Konstantinopels*, text volume, Berlin 1907, p. 68.
[5] D. Kuban, *Sinan'in sanatı*, op. cit., p. 69.

Interior of the Şehzāde Mosque with a view into the main dome, from Yerasimos, *İstanbul*[6].

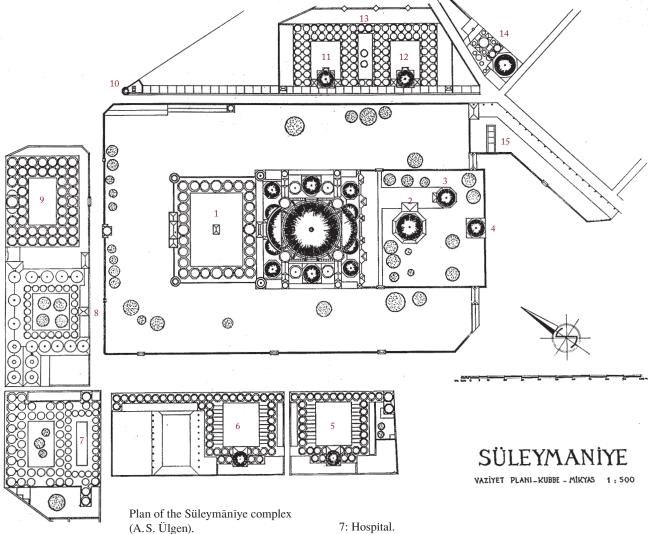
Türbe (mausoleum) of Şehzāde Meḥmed (A.S. Ülgen).

[6] St. Yerasimos, *İstanbul İmperatorluklar Başkenti*, İstanbul 2000, p. 257.

The Süleymānīye
in Istanbul

Our model:
Wood and plastic.
Domes of cast lead.
Scale ca. 1:150.
Measurement of the base plate: 155 × 125 cm.
Steel frame.
(Inventory No. F 01)

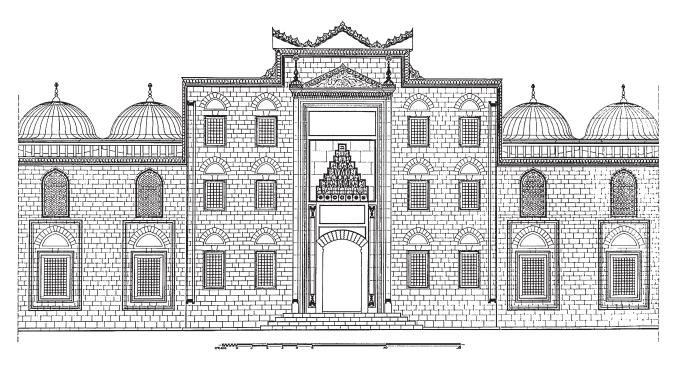
The Süleymaniye Camii (this is how the name of the mosque is written in modern Turkish) is, chronologically, the second grand mosque built by the architect Sinān. Together with its social and cultural institutions, it is perhaps the largest architectural complex created in the Ottoman Empire. The construction began in 957/1550 and was completed in 964/1557.[1] It is reported that Sultan Süleymān himself suggested the location for the construction and that he entrusted his architect Sinān with the ceremonial opening of the building at the time when the keys were handed over.[2]

Sinān raised the number of minarets to four. The two higher ones (76 metres each) facing the courtyard of the mosque have three balconies each (*şerefe*), the two smaller ones (56 metres each) towards the outer side of the courtyard have two balconies each.
Cornelius Gurlitt[3] finds the design of this mosque an improvement over that of the Bāyezīd Mosque in Istanbul: «The main dome and two half domes as cover of the central area.

[1] D. Kuban, *Sinan'in sanatı*, op. cit., p. 78.
[2] ibid., p. 78.

[3] *Die Baukunst Konstantinopels*, op. cit., p. 69.

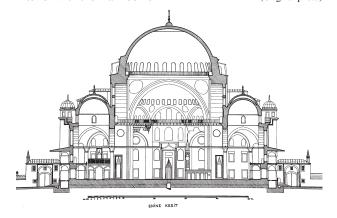
SÜLEYMANİYE

VAZİYET PLANI-KUBBE-MİKYAS 1:500

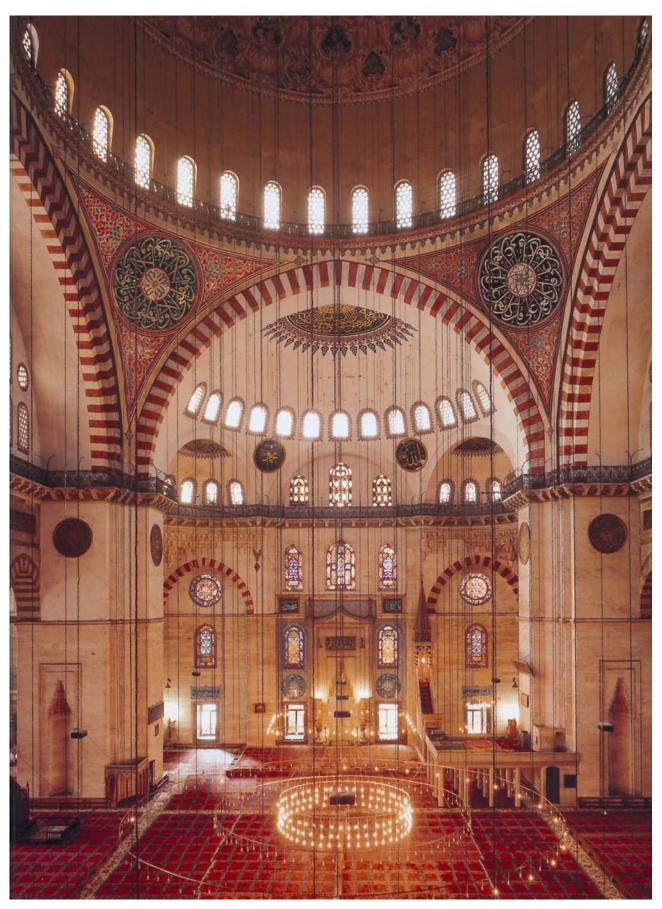
Plan of the Süleymānīye complex (A.S. Ülgen).

1: Mosque.
2: Mausoleum of Sultan Süleymān.
3: Mausoleum of Ḫürrem Sultan.
4: Lodge of the guards of the mausoleums.
5: First medrese.
6: Second medrese.
7: Hospital.
8: House for the poor.
9: Kitchen wing.
10: *Sebil* (well) and mausoleum of Sinān.
11: Third medrese.
12: Fourth medrese.
13: Caravanserai.
14: Bath wing (*ḥammām*)
15: Theological seminary (*dār al-ḥadīṯ*).

[81] The latter are supported by two diagonally placed half domes each so that a space [of] 52.4 metres is vaulted. The pillars, which have a strength of 7.44 to 7.56 metres in their broadest parts, however, do not give the impression of heaviness as a result of the structuring of the outline and the insertion of niches; in a very ingenious manner they are formed in such a way that each of the side aisles could be covered with five domes of different diameters. The arrangement shows the most complete mastery of composition so that the vaults could be formed organically everywhere. Of course, contemporary masters of the Renaissance, such as San Gallo, would have objected to the fact that the axes of the arches on which the domes rest do not coincide with those of the domes. Look at the arrangement of the middle domes of the side aisles: the difficulty is overcome clearly and plausibly by inserting an arch across those resting [sic] on the pillars of the external side, and through the extremely flexible shape of the stalactite spandrels.»

[82] «The domed areas at the four corners serve as entrance halls of the mosque. You enter the mosque through a door and before that through an arcade of the most delicate formation. The arcade in front of the Sultan's podium, particularly is decorated

Main portal of the Süleymānīye (A.S. Ülgen).

with great care. Between the corner rooms built-in balconies extend inside and outside; on the outside in two storeys, inside in one. The architecture of the pillars and arches belongs to the most noble and perfect of all that has been accomplished by Turkish architecture. The juxtaposition of the finely structured arcades with the massive structure of the main building which soars over them is likewise of the highest artistic subtlety.»[4]
All in all 138 windows provide light to the hall.[5]
«Behind the mosque, adjoining its kiblah side there is a garden enclosed by a wall with barred windows. Here is situated Süleymān's mausoleum, completed in [974/]1566, which is one of the most magnificent edifices of this type. Besides Süleymān himself, Sultana Süleymān (Ḫürrem Sultan, d. [965/]1558) and Aḥmed II (d.[1106/]1695) … are buried there.»

Interior with the main dome (Original photo)

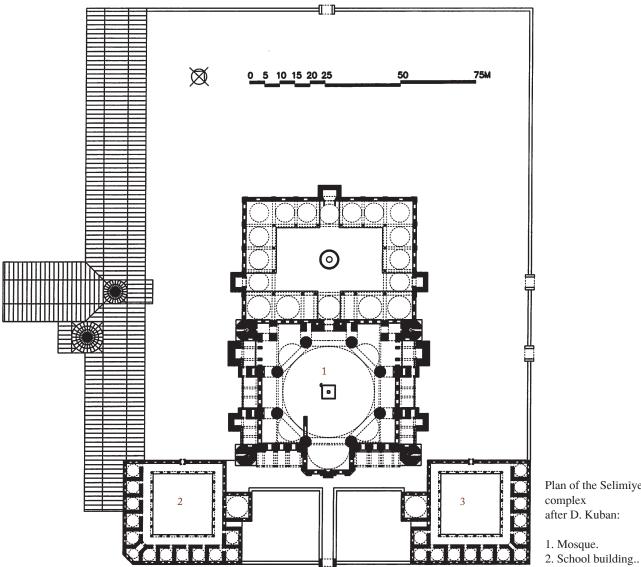
ENİNE KESİT

Section through the Süleymānīye (A.S. Ülgen).

[4] C. Gurlitt, *Die Baukunst Konstantinopels*, op. cit., pp. 69-70.
[5] ibid., p. 71.

Interior with view towards the miḥrāb (from St. Yerasimos, *Istanbul*, op. cit. p. 263).

The Selīmīye

Mosque

Our model:
Wood and plastic.
Domes of lead.
Scale ca. 1:100.
Measurement of the base plate:
100 × 100 cm.
(Inventory No. F 02)

The mosque in Edirne, written Selimiye Camii in modern Turkish, is the third grand mosque built by Miʿmār Sinān. It was built on the orders of the Ottoman Sultan Selīm II. The construction lasted from 976/1568 to the end of 982/(March 1575).[1] The seriously ill Sultan had passed away three months previously. The Selīmīye Mosque is generally thought to be the culmination of Sinān's life-work and of his experience and mastery of the architecture acquired during nearly half a century of intensive work. [85] He is said to have expressed himself in this spirit when he remarked that he had built the Şehzāde Mosque during his apprentice-

[1] D. Kuban, *Sinan'in sanatı*, op. cit., p. 133.

0 5 10 15 20 25 50 75M

1

2

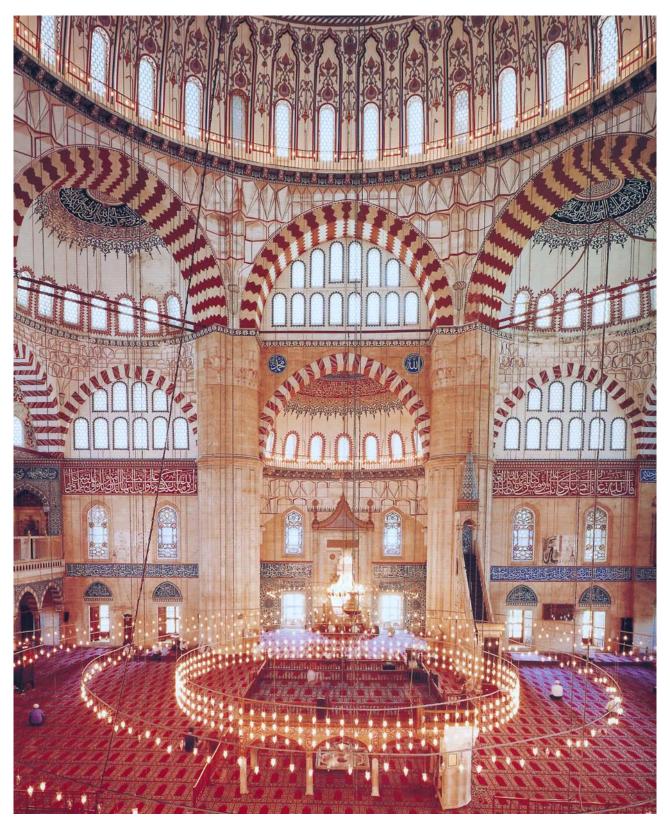
3

Plan of the Selīmīye complex after D. Kuban:

1. Mosque.
2. School building..

ship, the Süleymāniye Mosque during his period as a master architect, but he had reached the climax of his ability as an architect with the construction of the Selīmīye Mosque.[2]
«The mosque contains the main features common to all the larger complexes: the forecourt (haram) and the congregation hall or the prayer hall (cami). Both lie on the same level, approximately 1 metre above ground, and together form a closed rectangle of 60 metres width and 95 metres length, from the sides of which only the substructures of the minarets and an apse on the southern side protrude slightly. Almost half of this area is taken up by the forecourt. It is of rectangular shape and lies at right angles to the main axis of the building. The vaulted halls of roughly 8 metres or 9 metres width, to be found on all the four sides, surround an open courtyard of 37.40 to 24.80 metres.»
[86] «The basic form of the prayer hall also appears in its outer perimeter as a rectangle lying at right angles to the main axis, but it takes the shape of a regular octagon in the middle. This octagon

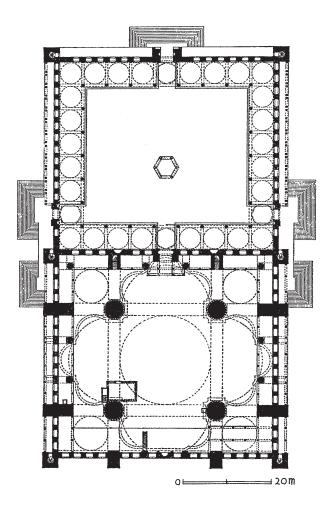
[2] D. Kuban, *Sinan'in sanatı*, op. cit., p. 127.

constitutes the basic form for the development of the centre of the hall proper. The remaining parts of the ground plan on both the sides of the octagon are used to extend the space for the hall, the side halls and balconies. The internal measurements of the main hall, when measured on the level ground in the rectangle, amount to about 45 to 35.90 metres. The width of the octagon is roughly 31.40 metres, the distance between the pillars being 10.50 metres.»[3]
«Three mighty main arches, separated by two smaller intermediate arches, are borne here by stately and polished granite pillars and reach, in rhythmic alternation, almost twice the height of the side halls. Crowned with three domes over the main arches, the middle one of which is raised to an even greater height and is structured particularly richly with ribbing, this part of the forecourt is an independent entrance hall of finely shaped proportions and monumental treatment and thus prepares the entry to the place of worship in a unique manner.»[4]
«A magnificent portal with niches, adorned with the richest forms of Ottoman art, decorated with stalactite formations and rich ornamentation, leads us now through the entrance hall into the main hall of the mosque, the hall of prayer or congregation. After passing through a semi-dark vestibule, formed by hanging carpets, we find ourselves immediately below the wide vault of the main dome. We find that our boldest expectations, already enhanced by the entrance hall that led us in, are far surpassed by this dome, which is vaulted above us. Eight massive pillars, which are almost cylindrical in outline, but structured in multiple ways, soar up, and from there two rows of mighty pointed arches rise in tiers one above the other, all of them serving the common purpose of bearing the vaulted dome, and producing an impressive effect due to the uniformity of their purpose.»[5]
The inner length of the diameter of the main dome, i.e. the distance of the walls and the pillars supporting the dome, is 31.50 metres.[6]

[3] Armin Wegner, *Die Moschee Sultan Selim's II. zu Adrianopel und ihre Stellung in der osmanischen Baukunst*, in: Deutsche Bauzeitung (Berlin) 25/1891/329-331, 341-345, 353-355, esp. p. 341.

[4] ibid., p. 341.
[5] ibid., p. 341.
[6] ibid., p. 342; D. Kuban, *Sinan'ın sanatı*, op. cit., p. 137. The corresponding length of the Ayasofya (Hagia Sophia) is 31.40 metres.

Interior of the Selīmīye Mosque, view to the west, with minbar (from St. Yerasimos, Istanbul, op. cit. p. 271).

The Sultan Aḥmed Mosque

Our model:
Wood and plastic.
Scale 1:100.
Measurement of the base plate: 130 × 100 cm.
Steel frame.
(Inventory No. F 03)

The Sulṭān Aḥmed Cāmiʿi is also known as the Blue Mosque because of the light blue colour of the interior. It was built at the orders of the Ottoman Sultan Aḥmed I (ruled 1012/1603-1026/1617). The architect was Meḥmed Āġā. The construction was commenced in 1609 when the ruler who ordered the construction of the mosque was but 19 years old. It was completed in 1616, and the Sultan lived only a year longer. It is reported that he took part in the foundation laying ceremony with a golden hoe.[1]

[1] Mücteba Ilgürel, art. *Ahmed I* in: Islâm Ansiklopedisi, vol. 2, İstanbul: Türkiye Diyanet Vakfı 1989, p. 33.

«Many consider this building to be the most beautiful of all imperial mosques; it may be so. Certainly the terraced arrangement of domes and half domes provides a magnificent view with the soft silvery grey of the stone and of the leaden roofs, with the gold of the ornaments added on the minarets and domes. This rich impression of the exterior is intensified even more by the number of minarets: there are six of them, that is, two more than those dis-

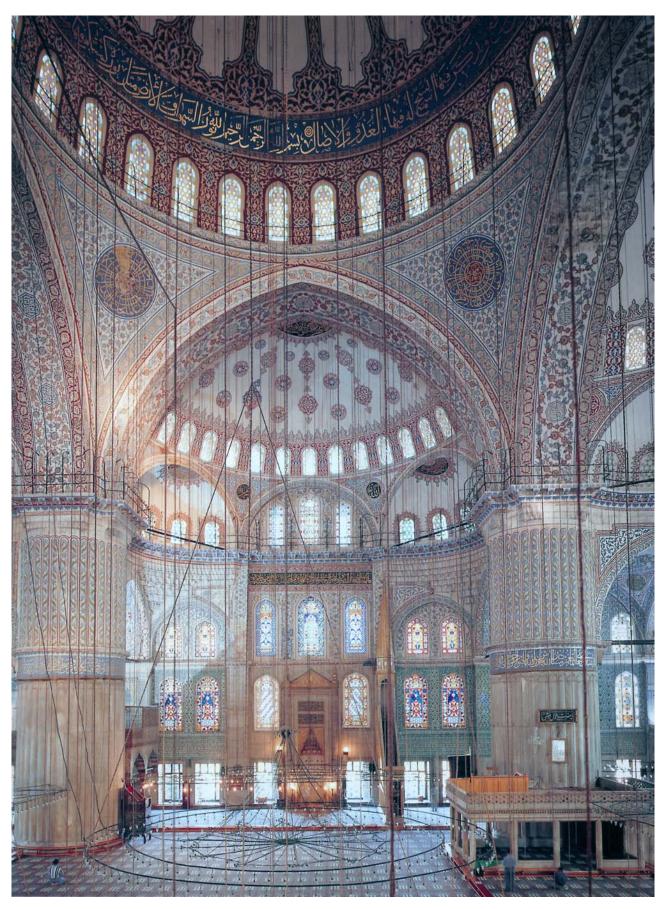
0 20m

Plan from J. Freely and H. Sumner-Boyd: *Istanbul*, Munich 1972, p. 152.

View into the main dome (Photo: K.O. Franke)

played by the other imperial mosques in Istanbul. Therefore this structure appears imposing without being [89] heavy. The charm which the observer vaguely feels retains more of the atmosphere in view of the massive size of these forms which are just a little bit softer and smoother than those of Sinān's grand mosques.»[2]

«The Blue Mosque is an almost square hall (51 metres long, 53 metres wide), vaulted over by a dome of 23.5 metres diameter and 43 metres height at the vertex. It is supported by four wide pointed arches which transmit the curvature of the dome over four spandrels to the square ground plan of the main hall, which is marked by the massive supporting pillars at its corners.»[3]

«Light streams into the interior through 260 windows which were once filled with coloured glass like the wall of the mihrab. There are plans for filling more windows once again with coloured inlaid glass so that at least some of the old impression is recreated of a hall that is not dim but lit in a subdued way.»[4]

«The endowments belonging to the entire complex of the mosque (küllīye) were appropriate to the size and cover a medrese (…), the Sultan's mausoleum, hospital and caravanserai, primary school, canteen for the poor and a bazaar. The hospital and the caravanserai were demolished in the 19th century, the canteen for the poor was incorporated into the building of the School of Industrial Arts on the southern side of the At Meydanı. The primary school was renovated recently; it is the building on the northern side of the outer enclosure wall of the mosque. The medrese, which is in fact rather big but appears small in relation to the mosque, lies outside the enclosure wall of the complex towards the north-east, very close to the exceptionally large mausoleum with the square ground plan. In this mausoleum … lies Aḥmed I next to his consort Kösem Sultan and three sons: Murād IV, ʿOs̱mān II and Prince Bāyezīd.»[5]

[2] J. Freely, H. Sumner-Boyd, *Istanbul*, op. cit., p. 149.
[3] ibid., p. 151.
[4] ibid., p. 152.
[5] ibid., pp. 153-154.

Interior of the Sulṭān Aḥmed Cāmiʿi, with view of the *miḥrāb* (from St. Yerasimos, *Istanbul*, op. cit., p. 333).

Chapter 12

Military Technology

Introduction

Probably in no other domain were the knowledge and achievements of other cultures adopted as quickly as in military technology. The rapid and wide-scale expansion resulting from the conquests by Muslims in the first century after their appearance on the stage of world history leads us to assume—of course not without historical documentation—that they quickly recognized the superior quality of their adversaries' weapons and appropriated that knowledge.

The adversaries who were initially superior to them included, besides the Byzantines, also the Persians. It is therefore not surprising that the oldest books preserved in Arabic literature on military technology turn out to be translations of works by the Persians of the Sassanid period or by Indians.[1] Moreover, the historian of science Ibn an-Nadīm, who lived in the 4th/10th century mentions an Arabic work on the use of a certain type of Greek fire (*Kitāb al-ʿAmal bi-n-nār wa-n-nafṭ wa-z-zarrāqāt fi l-ḥurūb*[2]) and a book on battering rams, catapults and «military stratagems» (*Kitāb ad-Dabbābāt wa-l-manǧanīqāt wa-l-ḥiyal wa-l-makāyid*[3]).

Against such a background we can appreciate better the report of the historian aṭ-Ṭabarī (d. 310/923) to the effect that the Abbasid Caliph al-Muʿtaṣim had deployed mobile battering rams at the conquest of the city of Amorium (southwest of Ankara) in 213/837 (see above, pp. 137 f.).

Without wishing to overrate the contribution in this field which is due to the Arab-Islamic world in the universal history of science, we must emphasize that the military technology also underwent a significant development in the Arab-Islamic area in the period between Late Antiquity and the so-called Renaissance. It goes without saying that the advances in fields like physics, chemistry and technology, made continuously for centuries since the 3rd/9th century in the Arab-Islamic world, would not remain without an impact on military technology. In their writings published between 1845 and 1858,[4] Joseph-Toussaint Reinaud and Ildephonse Favé have been able to extract, to a large extent, the contribution of the Islamic countries to the technology of weaponry. The results obtained by them from the study of the manuscripts of Arabic works on military technology which were accessible to them at that time and from information in historical works are to a large extent valid even today. Moreover, a few other important manuscripts and historical data that have in the meantime become available take us further. The results achieved by Reinaud and Favé and the views they held on the Arab-Islamic world in the history of military technology were taken into consideration rather well in the non-Arabist studies on the subject in the second half of the 19th century and the first half of the 20th century. On the other hand, it is striking that in studies from the second half of the 20th century onwards hardly any of it was taken note of,[5] with the exception of the commendable *History of* [94] *Greek Fire and Gunpowder* by J. R. Partington (1960), the relevant parts of *Science and Civilisation in China* (vol. 5, part VI, 1994) by Joseph Needham and *Zur Geschichte des mittelalterlichen Geschützwesens aus orientalischen Quellen* by Kalervo Huuri.

[1] *Fihrist* by Ibn an-Nadīm, ed. G. Flügel, Leipzig 1872, pp. 314-315.

[2] ibid., p. 315; J. Reinaud, *De l'art militaire chez les Arabes au moyen âge*, in: Journal Asiatique, sér. 4, 12/1848/193-237, esp. p. 196.

[3] *Fihrist*, op. cit., p. 315; J. Reinaud, *De l'art militaire*, op. cit., p. 196.

[4] Reinaud and Favé, *Histoire de l'artillerie*. 1ère partie: *Du feu grégeois, des feux de guerre et des origines de la poudre à canon*, vol. 1 (texte), vol. 2 (planches), Paris 1845; Reinaud and Favé, *Du feu grégeois, des feux de guerre, et des origines de la poudre à canon chez les Arabes*, les Persans et les Chinois, in: Journal Asiatique, sér. 4, 14/1849/257-327; Reinaud, *De l'art militaire chez les Arabes au moyen âge*, in: Journal Asiatique, sér. 4, 12/1848/193-237; Reinaud, *Nouvelles observations sur le feu grégeois et les origines de la poudre à canon*, in: Journal Asiatique, sér. 4, 15/1850/371-376.

[5] This was also noted with regret by Kalervo Huuri (*Zur Geschichte des mittelalterlichen Geschützwesens aus orientalistischen Quellen*, Helsinki and Leipzig 1941, p. 25): «In this history of artillery there are many lacunae. First of all it restricts itself exclusively to the situation in Antiquity and in Europe and does not deal with Oriental developments …»

As I now undertake to discuss some new elements which, in my view, were developed or discovered in the military technology of the Arab-Islamic world, I restrict myself at this point to the large crossbow, the counterweight trebuchet, gunpowder and firearms These are elements which appear as new inventions in the history of European military technology in the 13th or the 14th century.

a) Windlass Crossbow

Of the diverse types of the crossbow which already formed part of the artillery of the Greeks, Romans and Sassanid Persians, I mention here only the windlass crossbow which was drawn through a windlass (rack-and-pinion gear).[6] This crossbow, which is a variant of the large crossbow (qaus az-ziyār), is described in detail and illustrated in the extant *Tabṣirat arbāb al-albāb fī kaifīyat an-naǧāt fi l-ḥurūb* by Marḍī b. ʿAlī b. Marḍī aṭ-Ṭarsūsī, which was partly edited and translated into French by Claude Cahen in 1948.[7] The bow was called qaus bi-l-laulab. Its description in this book, which was written under Ṣalāḥaddīn (Saladin, ruled 569/1174- 589/1193), gives the impression that it was a well known weapon even at that time. It is also listed by the historian Ibn aṭ-Ṭuwair (b. 524/1130, d. 617/1220) among the weapons in the arsenal of the youngest Fatimid Caliph in Egypt of 467/1071.[8] According to his statement, an arrow weighed about 2200 grams The French historian Jean de Joinville reports that during the crusade of Louis IX in 1249 the Egyptians had shot at the French near Manṣūra, among others, four times from the windlass crossbow with Greek fire.[9]

The description of our Arabic sources confirms G. Köhler's[10] assumption that the windlass crossbow was «a normal crossbow which differed only in its larger dimensions from the stirrup crossbow [Arabic *qaus al-yad*] and was tautened by a windlass (tour) [Arabic *laulab*].» We can well imagine that it was this type which Emperor Frederick II in 1239 ordered a captain who was sailing to Accon to purchase there *tres bonas balistas de torno et de duobus pedibus* (Arabic *qaus al-ʿaqqār*).[11]
In the above-mentioned Arabic book[12] on military technology dedicated to Prince Ṣalāḥaddīn (Saladin) a crossbow with large dimensions is described in quite some detail. If I understand the author correctly, he is of the view that it was an achievement of his older contemporary Abu l-Ḥasan b. al-Abraqī al-Iskandarānī. Claude Cahen,[13] who edited the text, translated it into French and examined it, also understands the author's statement in the same sense and, based on this, refutes the view of Kalervo Huuri,[14] who claimed that the Mongols had brought the [95] Chinese pedestal crossbow to Persia in the 13th century.[15] The fact of the matter was the other way round, with the Mongols borrowing this improved crossbow from the Muslims.
According to the description of the book, that large crossbow (*qaus az-ziyār*) is said to have been the largest in its dimension, the farthest in its range and the most lethal in its effect. The edges of the square gun carriage are said to measure about 5.6 metres.

[6] G. Köhler, *Die Entwickelung des Kriegswesens und der Kriegführung in der Ritterzeit von Mitte des 11. Jahrhunderts bis zu den Hussitenkriegen*, vol. 3, Breslau 1887, p. 174.
[7] *Un traité d'armurerie composé pour Saladin*, in: Bulletin d'Études Orientales 12/1947-48/103-163, esp. pp. 110, 131-132, 156.
[8] ʿAbdassalām b. al-Ḥasan Ibn aṭ-Ṭuwair, *Nuzhat al-muqlatain fī aḫbār ad-daulatain*, ed. A. F. Saiyid, Cairo 1992, p. 134; Taqīyaddīn al-Maqrīzī, *al-Mawāʿiẓ wa-l-iʿtibār bi-ḏikr al-ḫiṭaṭ wa-l-āṯār*, Būlāq 1270, vol. 1, p. 417; K. Huuri, op. cit., p. 126.
[9] Reinaud and Favé, *Histoire de l'artillerie*. 1ère partie: *Du feu grégeois*, pp. 53-60; Joinville, *Histoire du roy saint Loys*, Paris 1668, pp. 39 ff.; K. Huuri, op. cit., p. 126; G. Köhler, *Die Entwickelung des Kriegswesens*, op. cit., pp. 175,187.
[10] *Die Entwickelung des Kriegswesens*, op. cit., p. 174.
[11] v. G. Köhler, op. cit., p. 175.
[12] *Tabṣirat arbāb al-albāb*, op. cit., p. 106.
[13] op. cit., p. 129.
[14] *Zur Geschichte des mittelalterlichen Geschützwesens*, op. cit., p. 123.
[15] Cahen (op. cit., p. 151) says: «Kalvero Huuri, n'ayant rencontré d'allusion certaine au qaus az-ziyār que dans des auteurs postérieurs à l'apparition des Mongols, considérait cet engin comme apporté par eux. Notre chapitre nous oblige à adopter une conclusion contraire, et à considérer cette arme comme née au plus tard sous Saladin, et par conséquent vraisemblablement apprise des Musulmans par les Mongols lorsqu'on la trouva employé chez eux. K. H. avait relevé un certain nombre de mentions du *ziyār* dans d'autres auteurs contemporains de Saladin (…), mais pensait que le mot avait un sens vague; nous sommes en droit de conclure qu'il avait dès lors son sens précis et que l'arme figure donc normalement dans les guerres contre Saladin et les Croisés entre 1187 et 1192, période à laquelle se réfèrent toutes les citations.»

Fig. from Marḍī, *Tabṣira*, MS Oxford, Bodl., Hunt. 264.

Illustration from *Leonardo da Vinci*, p. 291.

For operating it a team of about 20 persons was actually needed, but thanks to the technology used, one single man was sufficient to set it in motion. Its technical equipment included a windlass construction for drawing the bow. The length of the parts of the bow lying to the right and to the left of the shaft was about 3.3 metres each. The bows were made of several layers of thin plates of oak wood and animal horn which were sawn into shape and glued together.[16]

The strength of the bow amounted to about 35 cm in the large crossbows, about 24 cm in the medium pieces and about 12 cm in the small ones. The author states that the number of bows can be increased up to three and demonstrates this with the following illustrations (see fig. on the right above): This type of large crossbow seems to have inspired the imagination of Leonardo da Vinci to think of a gigantic construction:[17]

From the Islamic world a wooden bow with a length of about 2 metres is preserved in the Musée de l'Armée (Hôtel National des Invalides) in Paris, which institution kindly provided us with the following illustration. The bow is said to come from Syria and belongs to the 6th/12th century (see ill. p. 96). Composite bows (laminated with wood, horn, sinews and glue) had been the preferred weapons for hunting and warfare in the Middle East since pre-Islamic times. It is therefore unlikely that to this method of construction was only restorted for the bows of very large crossbows. Moreover, there is the possibility that the smaller crossbows contained bows of steel. Our 12th century source is silent on this count but its illustrations create the impression that the smaller crossbows must have been of metal (steel in our case). The earliest mention known so far of a steel bow goes back to the first half of the 8th/14th century. The anonymous source dating from that time enumerates the steel bows as «Indian bow» (*qisīy hindīya*) in a list of weapons indispensable to the army.[18] It is likely that bows of Damascene steel were meant by this.[19] We learn about the earliest known use of steel bows in Europe from an inventory dating from 1435.[20]

[16] *Tabṣirat arbāb al-albāb*, op. cit., p. 108; French transl. pp. 129-130; Bernhard Rathgen, *Das Geschütz im Mittelalter*, Berlin 1928, p. 635; Volker Schmidtchen, *Kriegswesen im späten Mittelalter. Technik, Taktik, Theorie*, Weinheim 1990, p. 169.

[17] *Leonardo da Vinci. Das Lebensbild eines Genies*, Wiesbaden and Berlin: Emil Vollmer 1955, p. 291.

[18] v. Ferdinand Wüstenfeld, *Das Heerwesen der Muhammedaner nach dem Arabischen*, in: Abhandlungen der Königlichen Gesellschaft der Wissenschaften (Göttingen) 26/1880, Historisch-philologische Classe, No. 1 and 2, esp. No. 2, p. 2 (reprint in: Ferdinand Wüstenfeld, *Schriften zur arabisch-islamischen Geschichte*, vol. 2, Frankfurt 1986, pp. 1-109, esp. p. 79).

[19] K. Huuri, *Zur Geschichte des mittelalterlichen Geschützwesens*, op. cit., pp. 120, 208.

[20] G. Köhler, *Die Entwickelung des Kriegswesens*, op. cit., pp. 181-182.

Fig.: Bow, Paris, Musée de l'Armée (6th/12th c.).

b) Counterweight Trebuchet

In his attempt to explain the progress in the technology of weaponry which gradually took place in Europe in the 7th/13th century, G. Köhler[21] in 1887 argued with regard to the new artillery system of that time: «However, at the beginning of the period we encounter the Arabs everywhere as those who have the most experience in things of this kind.» But he thought it necessary to remark: «Although it is very likely that the Byzantines were the inventors of the new machines and that the Arabs adopted these new machines from them, the Byzantine influence cannot be proved in this case.» In the following passage he explains[22] the innovation of ballista with counterweight used since the beginning of the 7th/13th century as compared to the catapults already known to the Greeks and the Sassanids: «The human strength applied to the short lever in the case of the Petraria is replaced by a counterweight, due to which not only is the operating team reduced but the initial velocity of the projectile is also increased considerably, because the falling counterweight attached to the short lever arm increases its speed as a consequence of the velocity of fall, and this is also transmitted to the projectile on the long arm of the lever.»

In the course of his rather detailed treatment of the subject, Köhler expresses the assumption that this piece of artillery reached Europe via Italy[23] and the Spanish Arabs.[24]

Compared to the much more extensive material on the European side until the middle of the 20th century researchers did not have many Arabic sources at their disposal. For a chronological evaluation of counterweight trebuchets used in both Europe and the Arab world, to judge from illustrations and descriptions, [97] it was primarily the book on the military technology by the Mamluk tournament master Ḥasan ar-Rammāḥ (d. 694/1295) which since 1845 has offered (see below, p. 99) a terminus a quo or ad quem.

The book, which was dedicated to the ruler Saladin in the second half of the 6th/12th century, and which was partly edited by Claude Cahen in 1948, gives us short descriptions of various types of catapults, an «Arabic one», a «Persian or Turkish one» and a «Byzantine or Frankish one». The most reliable was the Arabic catapult, the easiest to use was the Turkish variety. Unfortunately the descriptions are very brief and do not permit an exact idea of details. Among the illustrations added in profile, the form of the beam of a counterweight trebuchet is remarkable. On the other hand the book offers a complete pictorial depiction of a «Persian» counterweight trebuchet which served as a crossbow and at the same time as a catapult. It is a very advanced type. The brief description and the illustration of parts of the catapult known as «Byzantine or Frankish» give the impression of a projectile with small levers.[25]

Clearer illustrations of counterweight trebuchets are provided a century later by the Mamluk tournament master Naǧmaddīn Ḥasan ar-Rammāḥ (d. 694/1295, see below p. 99). More advanced versions of this type appear in the *al-Anīq fi l-manāǧnīq* by Ibn Aranbuġā az-Zaradkāš (written 775/1374). This author, who was in the service of the Mamluks,

[21] G. Köhler, *Die Entwickelung des Kriegswesens*, op. cit., pp. 173-174.
[22] ibid., p. 190.
[23] ibid., p. 194.
[24] ibid., pp. 195-196.
[25] cf. the remark by Cl. Cahen on the text of the *Tabṣirat arbāb al-albāb*, op. cit., p. 158.

gives illustrations of two highly advanced forms of the counterweight trebuchets. He calls one of these *qarābuġā* («black bull»). It served for hurling heavy stone balls and was provided with a degree-meter for regulating the range and for calculating the aim, and also with a block and tackle and a windlass for increasing its effectiveness.
After these brief remarks on the origin and development of counterweight trebuchets, we may draw attention to some reports on their dissemination outside the Islamic world as well.
K. Huuri[26] compiled some information on the quite early use of the counterweight trebuchet in Europe at the beginning of the 7th/13th century. He also refers to several European sources in which the very advanced type is mentioned[27] at the siege of Acre (ʿAkkā) by the Muslims in 1291 as a large sensational machine under the name *caraboga* (*caabouhas*, *carabaccani*); on this weapon more details are available now in the book by Ibn Aranbuġā az-Zaradkāš. According to Arabic sources, 92 (or more) stone catapults (*manǧanīq*) were employed at the siege.[28] Of great importance in this connection are doubtless the reports of the Chinese and Persian sources on the question when and how the type of the large counterweight trebuchet reached the Chinese. It is reported that Kublai Khan, the grandson of Genghis Khan and founder of the Eastern Mongol empire, encountered bitter resistance at his attempt, begun in the year 1268, to take Sūng-China. He encountered this resistance particularly at the siege of the two northern, strategically important, cities of Hsiāng-Yáng and Fán-Chéng. At the suggestion of one of his commanders, Kublai ordered two engineers «from the West», from the Arab-Islamic territories, to be fetched with the order to build large counterweight trebuchets. With the help of the machines built by these two engineers, Ì-Ssū-Mă-Yīn (Arabic Ismāʿīl) and À-Lăo-Wă-Tīng (Arabic ʿAlāʾaddīn), Kublai succeeded in conquering the two cities in 1272 and 1273, and thus the Mongols secured their rule over China. The trebuchet introduced in this manner into China was called *huí-huí* («Muslim») *phao*.[29]
[98] Chèng Ssū-Hsìao, a contemporary chronicler wrote the following about this:
«The [Mongol] bandits used Muslim trebuchets against the city of Hsīang-Yáng, whose towers and walls they destroyed with alarming effect, so that [the governor and commander] [Lŭ] Wén-Huàn was very concerned … The type of ‹Muslim trebuchet› originally came from the Muslim countries. It was stronger than the common trebuchets. In the case of the largest of them, the wooden frame stood over a depression in the ground. The projectiles measured several feet in diameter. When they fell to the ground they made a hole three or four feet deep. When [the artillerists] wanted to shoot over a large distance, they raised the [counter] weight and pulled it further back [on the stock]; when they had a shorter aim, they put [the weight] further to the front, closer [to the fulcrum].»[30] In conclusion, it may be mentioned that Leonardo da Vinci left behind a remarkable sketch of a counterweight trebuchet (see our model below, p. 119).[31] There he puts a wheel around the axis of the beam, which seems to fulfil the function of a distance regulator. D. Hill[32] drew attention to this sketch. J. Needham[33] takes the view that Leonardo heard about the trebuchet via Mariano Taccola[34] (d. ca. 1458). In my opinion, however, Leonardo's sketch is far removed from Taccola's account. His distance regulator and the beam strengthened with several bundles of rope are reminiscent of an Oriental model.

[26] *Zur Geschichte des mittelalterlichen Geschützwesens*, op. cit., pp. 62 ff.
[27] ibid., pp. 174-175.
[28] Al-Maqrīzī, *Kitāb as-Sulūk li-maʿrifat duwal al-mulūk*, vol. 1, part 3, Cairo 1939, p. 764; E. Quatremère, *Histoire des sultans mamlouks de l'Égypte*, vol. 2, Paris 1842, p. 125; cf. K. Huuri, op. cit., p. 173.

[29] Reinaud and Favé, *Du feu grégeois, des feux de guerre, et des origines de la poudre à canon chez les Arabes*, les Persans et les Chinois, in: Journal Asiatique, sér. 4, 14/1849/257-327, esp. pp. 292-304; J. Needham, *Science and Civilisation in China*, vol. 5, part 6, pp. 219-221.
[30] J. Needham, op. cit., p. 221.
[31] *Leonardo da Vinci*, op. cit., p. 294.
[32] *Trebuchets*, in: Viator. Journal of the Center for Medieval and Renaissance Studies (Los Angeles) 4/1973/99-114 (reprint in: D. R. Hill, *Studies in Islamic Technology*, Variorum Collected Studies Series 555, 1998, No. XIX), esp. p. 104.
[33] *Science and Civilisation in China*, vol. 5, part 6, pp. 204-205.
[34] See G. Sarton, *Introduction to the History of Science*, vol. 3, part 2, p. 1552.

c) Fire Arms

In the first decade of their expansion when they laid siege to cities, Muslims made use of catapults (*manǧanīq*) inherited from the Sassanids or the Yemenites;[35] likewise they did not fail to make use of the ‹Greek fire› which they had taken over from the Byzantines. It is recorded that at the siege of Constantinople in 97/715 they used the pyrotechnical effect of *nafṭ* (naphta).[36] As was already mentioned (see above, p. 94), an Arabic book on Greek fire was written in the early Abbasid period, certainly before the 4th/10th century.

To be sure, for this effective weapon, which was used for centuries not only in the Arab-Islamic world, different formulas were developed in the course of time. About a rather elaborate composition from the 13th century, we are informed by the Liber ignium ad comburendos hostes,[37] which probably originated at the end of the century. The little booklet, preserved in Latin and containing about 6 pages, is ascribed to a certain Marcus Graecus and consists of a collection of formulas without any recognizable order.[38] According to J. R. Partington,[39] the author was a «Jew or Spaniard» of the 12th or the 13th century.[40] The main formula of the Liber ignium consists of «pure sulphur, cream of tartar, Sarcocolla (the resin of a Persian [99] tree of the same name), pitch, sodium chloride and paraffin (naphta), besides common oil.»[41] From the most advanced formula of the Liber ignium, the knowledge of saltpetre and gunpowder can be deduced. However, saltpetre is not mentioned in connection with Greek fire, but leads «in combination with sulphur and coal to real gunpowder», and this is restricted to the «manufacture of the rocket and the cannon cracker.»[42]

On the approximate date and the value of the little book for the history of science, Joseph-Toussaint Reinaud and Ildefonse Favé covered the essential points in their studies[43] published in 1845 and 1849. They were able to refer to a wealth of historical reports from Arabic, Persian and Chinese sources, above all to the book on military technology by Ḥasan ar-Rammāḥ (d. 694/1295) which is preserved in different editions with the title *Kitāb al-Furūsīya wa-l-manāṣib al-ḥarbīya*.[44] Reinaud and Favé came to the conclusion that the date or origin of the *Liber ignium* should be adduced as between 1225 and 1250.[45] After many years of study of the subject, the two scholars reached the following conclusion on the question of the origin of firearms: «In Antiquity the Greeks and the Romans used certain materials for burning, the composition of which was, however, restricted to very simple formulas. The military art of fireworks, which was made use of by the Byzantines in late Antiquity and which did them at first the greatest service, had been improved remarkably, but the final improvements seem to have come from the Chinese. At least this much is beyond doubt, that the Chinese were the first to recognize that substance which was to change the production of incendiary material, namely saltpetre. When the Arabs took over from the Chinese a certain number of incendiary materials, they learnt from them how to mix the three substances which constitute gunpowder: saltpetre, sulphur and coal.»[46] Their progress in the field of chemistry or at least in its application had made it possible for the Arabs to improve the purification of

[35] K. Huuri, *Zur Geschichte des mittelalterlichen Geschützwesens*, op. cit., p. 134 ff.

[36] v. anon., *al-ʿUyūn wa-l-ḥadāʾiq fī aḫbār al-ḥaqāʾiq*, ed. J. de Goeje, Leiden 1869, p. 24; Marius Canard, *Textes relatifs à l'emploi du feu grégeois chez les Arabes*, in: Bulletin des Études Arabes (Algier) 6/1946/3-7.

[37] On most of the editions and translations, see Sarton, *Introduction*, op. cit., vol. 2, part 2, pp. 1037-1038; the most recent edition with an English translation is by Partington, *A History of Greek Fire*, op. cit., pp. 42-57.

[38] Partington, op. cit., p. 58.

[39] ibid., p. 60.

[40] Partington (p. 60) says: «[Henry V. L.] Hime thought that the author or translator was not a Greek or Muslim (who never used the name ‹Greek fire›), but a Jew or Spaniard who either did not know the Latin names for some Arabic words or thought them so familiar that they need not be translated (alkitran and zembac are untranslated; the Arabic nuḥās aḥmar for copper becomes aes rubicundus not cuprum, …).»

[41] G. Köhler, *Die Entwickelung des Kriegswesens*, op. cit., p. 168.

[42] ibid., p. 169.

[43] *Histoire de l'artillerie*. 1ère partie: *Du feu grégeois*, *des feux de guerre et des origines de la poudre à canon*, Paris 1845 and *Du feu grégeois, des feux de guerre, et des origines de la poudre à canon chez les Arabes, les Persans et les Chinois*, in: Journal Asiatique, sér. 4/1849/257-327.

[44] cf. C. Brockelmann, *Geschichte der arabischen Litteratur*, 1 suppl. vol., p. 905; ed. by ʿĪd Ḍaif al-ʿAbbādī, Baghdad 1984 and Aḥmad Y. al-Ḥasan, Aleppo 1998.

[45] *Du feu grégeois*, op. cit., (1849), p. 282.

[46] Reinaud and Favé, *Du feu grégeois*, op. cit., (1849), p. 260.

saltpetre considerably.[47] According to Reinaud and Favé, the Chinese discovered saltpetre and were the first to use it for the manufacture of fireworks. They were also the first to mix this substance with sulphur and coal and to recognize the propulsion power produced by burning the mixture. This led them to the idea of constructing rockets. As far as the Arabs are concerned, they had recognized the explosive power of gunpowder, used it, and had thus invented firearms[48]
Despite the observation that the Chinese had known saltpetre and its explosive character even before the 13th century, the question still remains as to whether the Arabs owe this knowledge to the Chinese or whether it is an independent development on their part. Until now the discussion of the subject started from the assumption that saltpetre, the main element of gunpowder, was unknown before the 13th century in the Arab-Islamic world. The discussion relied primarily on the earliest mention of saltpetre outside China, namely in the book of simple remedies (*al-Ǧāmiʿ li-mufradāt al-adwiya wa-l-aġḏiya*) by ʿAbdallāh b. Aḥmad Ibn al-Baiṭār[49] (d. 646/1248) where it is mentioned that the substance was known by the name of *bārūd* among the scholars of the Maghrib.
[100] However, we learn from a quotation in the history of medicine by Ibn Abī Uṣaibiʿa (d. 668/1270) that the physician ʿAbdallāh b. ʿĪsā Ibn Baḫtawaih (d. ca. 420/1029) described in detail the use of saltpetre for the manufacture of artificial ice in his book *Kitāb al-Muqaddimāt* or *Kanz al-aṭibbā'*.[50] E. O. von Lippmann pointed this out in 1906.[51]

The earliest mention in Arabic writings known so far of the use of saltpetre for the manufacture of gunpowder was identified by Reinaud and Favé[52] (middle of the 19th century) in the Paris manuscript of the book by Ḥasan ar-Rammāḥ (d. 694/1295). They also found the description of a cannon and a gun (see below, p. 133) in the manuscript of an important anonymous book on the art of warfare (*al-Maḫzūn fī ǧamīʿ al-funūn*), preserved at St. Petersburg.[53] This convinced the two scholars that the discovery of the propulsion power of gunpowder had taken place in the Arab-Islamic world. They had to revise their opinion that the place where gunpowder was first used is said to have been in Eastern Europe, in the region along the Danube.[54]
On the basis of the Petersburg manuscript, Reinaud and Favé came to the conclusion that the power of propulsion of gunpowder must have been known in the Arab-Islamic world at the latest in the second half of the 8th/14th century and this conclusion was confirmed by the *Kitāb al-Anīq fi l-manāǧnīq* by Ibn Aranbuġā az-Zaradkāš (written in 774/1373), the manuscript of which was discovered subsequently. This illustrated manuscript, preserved in the library of the Topkapı Sarayı (Ahmet III, 3469),[55] contains illustrations of quite advanced types of cannon. Of course, neither the lifespan of Ibn Aranbuġā az-Zaradkāš nor the likely date of composition of the anonymous *Kitāb al-Maḫzūn*

[47] ibid., p. 261.
[48] Reinaud and Favé, *Du feu grégeois*, op. cit., (1849),p. 327.
[49] ed. Cairo 1291 H., vol. 1 (reprint Islamic Medicine, vol. 69, Frankfurt 1996), p. 30; French transl. L. Leclerc, *Traité des simples*, vol. 1, Paris 1877 (reprint Islamic Medicine, vol. 71, Frankfurt 1996), p. 71; see Reinaud and Favé, *Histoire de l'artillerie*. 1ère partie: *Du feu grégeois*, op. cit., pp. 14-15.
[50] *ʿUyūn al-anbā' fī ṭabaqāt al-aṭibbā'*, ed. A. Müller, vol. 1, Cairo 1299 H. (reprint Islamic Medicine, vol. 1, Frankfurt 1995); pp. 82-83.
[51] in: *Abhandlungen und Vorträge zur Geschichte der Naturwissenschaften*, vol. 1, Leipzig 1906, pp. 122-123, see F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 3, p. 335.
[52] v. particularly *Du feu grégeois* ... (1849), op. cit., p. 261 and *De l'art militaire*, op. cit., p. 200.
[53] Current shelf mark number C 686, see A. B. Chalidov, *Arabskije rukopisi Instituta Vostokovedenija*, vol. 1, Moscow 1986, p. 493.
[54] *Du feu grégeois* ... (1849), op. cit., p. 309. For the analysis of the MS (here with the title *Kitāb al-maḫzūn wa-ǧamīʿ al-funūn*) see Alexis Olénine, *Notice sur un manuscrit du Musée Asiatique de l'Académie Impériale des Sciences de St.-Pétersbourg*, in: Bernhard Dorn, *Das Asiatische Museum der Kaiserlichen Akademie der Wissenschaften zu St. Petersburg*, St. Petersburg 1846, pp. 452-460; J. Reinaud, *De l'art militaire chez les Arabes au moyen âge*, in: Journal Asiatique, sér. 4, 12/1848/193-237, esp. pp. 203-205, 218-219, 221, 223, 226-227 and Reinaud and Favé, *Du feu grégeois* ... (1849), op. cit., pp. 309-314 (where the authors revise their earlier view on the discovery of the propulsion power of gunpowder in favour of the Arabs).
[55] v. H. Ritter, *La Parure des Cavaliers und die Literatur über die ritterlichen Künste*, in: Der Islam 18/1929/116-154, esp. pp. 150-151. The date on the title page of the manuscript is erroneous; the book was dedicated to Mängli Buġā (d. 782/1380); «on fol. 58b and 126a there is a colophon each of 21st Ram. 774, fol. 181b one of Ǧum. II 775» (Ritter).

(8th/14th c.) can serve as the upper limit of the emergence of the first firearm. Both authors, like their predecessors and successors, recorded in their respective books the knowledge of their times and of their geographical regions. They were not concerned with the question of the origin and the time of appearance of the objects, but with the description of the state of affairs as it was known to them at that time. Consequently the manuscript of the book by Ibn Aranbuġā with its date 774/1372 gives us a terminus ad quem, not a terminus a quo for the origin of firearms in the Arab-Islamic world.

The earliest reference to date to the use of a firearm in the Arab-Islamic world is to be found in connection with the siege of the city of Siǧilmāsa in 672/1273. The well-known historian Ibn Ḫaldūn reports in his historical work that against Siǧilmāsa the Merinid Sultan Abū Yūsuf Yaʿqūb (ruled 656/1258-685/1286) had employed manāǧnīq (counterweight trebuchets), *ʿarrādāt* (crossbows) and *hindām an-nafṭ*, a weapon where iron bullets were discharged out of a «magazine» (*ḫizāna*) after igniting the gunpowder.[56] Reinaud and Favé, who were the first to draw attention to this statement, doubted its veracity [101], primarily because it was not confirmed by contemporary sources.[57]

As reported by Lisānaddīn Ibn al-Ḫaṭīb in his history of Granada, roughly 60 years later, in 724/1324, the Nasrid Sultan Abu l-Walīd Ismāʿīl (ruled 713/1314-725/1325) bombarded the fortress of Iškar (Huescar, ca. 110 km to the north-east of Granada) held by Christians, «and hurled a hot iron bullet out of the largest instrument that functioned with naphta …» (*ramā bi-l-āla al-ʿuẓmā al-muttaḫaḏa bi-n-nafṭ kurat ḥadīd muḥmāt* …).[58] In a following verse the thunder of the cannons is compared to the thunder of the heavens.

The information by Ibn al-Ḫaṭīb attracted the attention of scholars even in the 18th century. The Spanish orientalist M. Casiri[59] translated it into Latin. From him it was taken over, among others, by the historian José Antonio Conde[60] (1765-1820). In Casiri's reproduction of the passage the word «iron» is missing, probably as a consequence of the manuscript used by him. That was one reason why a number of scholars wondered whether Ibn al-Ḫaṭīb could really have meant a cannon[61] or whether it could not have been a large trebuchet instead.[62] Some reports in Spanish chronicles give information about the firearms used in the battles between Christians and Muslims in the years 1331, 1340 and 1342.[63] I shall let G. Köhler[64] make the concluding remark on this subject: «These statements have to be understood in the context of Arabic literature in order to conclude that since 1325 they actually refer to firearms and that the Arabs are the ones who introduced them to the Occident.»

d) Grenades and hand grenades

The sphero-conical vessels unearthed in archeological excavations in Central Asia, in Persia and in the Volga region were considered for a long time to be architectural ornaments, containers of quicksilver or holy water, or even lamps. That they are grenades and hand grenades is an idea which began to only gain ground towards the end of the 1920s. The pioneer of this new interpretation was Wsewolod von Arendt.[65] The vessels, large numbers of which

[56] *Taʾrīḫ Ibn Ḫaldūn* ed. Ḫalīl Šaḥāda and Suhail Zakkār, Beirut 1981, vol. 7, p. 249.

[57] *Histoire de l'artillerie.* 1ère partie: *Du feu grégeois*, op. cit., pp. 73-77; cf. J. R. Partington, *A History of Greek Fire*, op. cit., p. 191.

[58] *al-Iḥāṭa fī aḫbār Ġarnāṭa*, ed. M. ʿA. ʿInān, vol. 1, Cairo 1955, p. 398; E. Quatremère, *Observations sur le feu grégeois*, in: Journal Asiatique, sér. 4, 15/1850/214-274, esp. pp. 255-257; I.-S. Allouche, *Un texte relatif au premiers canons*, in: Hespéris (Paris) 32/1945/81-84; G. S. Colin in: Encyclopaedia of Islam. New Edition, vol. 1, Leiden 1960, col. 1057.

[59] *Bibliotheca Arabico-Hispana Escurialensis*, vol. 2, Madrid 1770, p. 7.

[60] *Historia de la dominación de los Arabes en España*, Paris 1840, p. 593 (not seen), see Reinaud and Favé, *Histoire de l'artillerie.* 1ère partie: *Du feu grégeois*, op. cit., p. 70.

[61] Thus Quatremère, *Observations sur le feu grégeois*, op. cit., pp. 258 ff.; G. Köhler, *Die Entwickelung des Kriegswesens*, op. cit., pp. 222-223.

[62] On this, v. J. R. Partington, *A History of Greek Fire*, op. cit., pp. 191-193, 228.

[63] Reinaud and Favé, *Histoire de l'artillerie.* 1ère partie: *Du feu grégeois*, op. cit., pp. 70-72; G. Köhler, *Die Entwickelung des Kriegswesens*, op. cit., p. 223; J. R. Partington, *A History of Greek Fire*, op. cit., pp. 191, 193-195.

[64] *Die Entwickelung des Kriegswesens*, op. cit., p. 223.

[65] *Die sphärisch-konischen Gefäße aus gebranntem Ton*, in: Zeitschrift für historische Waffen- und Kostümkunde (Dres-

are preserved, show unusual strength and have a strikingly thin neck. Some specimens found in Syria carry inscriptions like *fatḥ – fatḥ* («victory – victory»), *bi-Ḥamā* («in [the city of] Ḥamā») or blessings.

Referring to the places where these grenades originated from or where they were found, Arendt says the following: «We encounter the form of the sphero-conical vessels throughout the Muslim East.»

«Indeed, Islam confronts us as a factor in the dissemination of this object which Islam employed in its victorious march as a weapon of war until it is superseded by firearms»[66]

[102] According to Arendt's conjecture, those vessels contained both incendiary materials like «Greek fire» and explosives: «There is no doubt about the explosive power of the contents of the grenades; this is attested by the fragments of these extraordinarily hard vessels piled up in the moats of old fortresses. Therefore we cannot consider the old clay grenades as mere incendiary projectiles. Their effect would have been too little for Asian cities and fortresses, which had too little inflammable material.»[67]

«That almost all the vessels are provided with a neck which has a narrow part allows us to draw conclusions about the way the grenades were thrown. The narrow part seems to have been intended to be encircled by a fine cord. It is quite likely that the grenades were carried during the campaign on a cord which encircled the neck of the vessel and whose other end was fastened to the belt or the saddle and that the cord was then used for throwing.»

«The grenade may have been hurled with a circular sweep, with the cord playing the role of a sling, which must have enhanced the flight range of the grenade.»[68]

Arendt was able to base his research on the material at his disposal in the Historical Museum in Moscow. He assumed that there was a connection between this material and the type of grenade found in Damascus, which was known to him indirectly.[69] He dated the vessels, richly decorated with ornaments, between the 7th/13th and the 8th/14th centuries.[70] He regretted that he did not succeed «in analyzing the minute parts which could be taken out of the vessel.»[71]

Arendt's wish was fulfilled in the subsequent decades thanks to the efforts of Maurice Mercier.[72] As a French naval officer in Syria he had, since 1916, been in frequent contact with the curators of the Cairo museum and had secured possession of a number of such vessels which had been found during archeological excavations in the old part of Cairo.[73] In the course of his examinations he was convinced that the specimens found in Cairo belonged to the weaponry used by the Egyptians at the siege of the city[74] by Amalrich I in 1168.[75] For this conclusion he relied on the report of the historian al-Maqrīzī, according to which Šāwir b. Muǧīr as-Saʿdī, the governor of Upper Egypt (d. 564/1169), had sent 20,000 *qārūrat nafṭ* and 10,000 *mašʿal nār* to Cairo on that occasion.[76] He makes a distinction between grenades with gunpowder and those with liquid incendiary material. He found both these varieties in the above-mentioned (see above, p. 94) defences of al-Manṣūra against the army of Louis IX in 1249.[77]

Chemical analyses which Mercier commissioned of preserved grenades of Cairo, Alexandria, Jerusalem, Damascus and Tripoli (in modern Lebanon) convinced him—of course not without the support of historical evidence—that the knowledge of the Arab-Islamic countries regarding saltpetre goes back to a considerably earlier period than is generally supposed. In 1937 he published the result of

den) N. F. 3/1931/206-210.

[66] ibid., p. 209.

[67] *Die sphärisch-konischen Gefäße*, op. cit., p. 209.

[68] ibid., p. 210.

[69] ibid., p. 209.

[70] ibid., p. 209.

[71] ibid., p. 209.

[72] He recorded his results in his *Le feu grégeois. Les feux de guerre depuis l'antiquité. La poudre à canon*, Paris 1952.

[73] ibid., p. 94.

[74] v. René Grousset, *Histoire des croisades et du Royaume Franc de Jérusalem*, vol. 2, Paris 1935, pp. 525-534.

[75] M. Mercier, op. cit., pp. 98 ff., 104, 125 ff.

[76] *Kitāb al-Mawāʿiẓ wa-l-iʿtibār bi-ḏikr al-ḫiṭaṭ wa-l-āṯār*, op. cit., vol. 1, p. 338; M. Mercier, *Le feu grégeois*, op. cit., p. 73.

[77] M. Mercier, *Le feu grégeois*, op. cit., pp. 77, 125.

the analysis of the grenades found in 1798 in the «old castle of the lighthouse of Alexandria».[78] He published the reports of the chemical institutes which made the necessary analyses, together with photos of a number of preserved grenades from the Arab-Islamic world, in the appendix of his *Le feu grégeois*, which appeared in 1952.

[103] Among his various conclusions,[79] what is important for us is view that the year 1168 is the terminus ad quem for grenades filled with dry explosives, because the Egyptians used grenades of this type at the siege by Amalrich I. It was the grenade or the hand grenade which is mentioned in the book by Ḥasan ar-Rammāḥ as *qawārīr* («vessels», singular *qārūra*,) or as *karrāz šāmī* («Syrian vessel»).[80]

Then in 1959, as part of an article on the *Antiquités syriennes*, Henri Seyrig,[81] an archeologist, posed the question about the function of these sphero-conical vessels of burnt clay, which had been understood until then in quite different ways as containers for liquids (quicksilver, perfume or beverages), as grenades or as aelopiles (see below). He is inclined to dismiss the first two explanations because of the physical composition of the vessels. He points out that, first of all, they are pointed at the bottom and could, therefore, not be placed in an upright position, secondly that they could not hold enough liquid to serve as drinking vessels and thirdly that they had very narrow necks with a diameter of 3 to 5 mm, mostly between 4 and 5 mm, so that liquids could not be poured in easily.[82] Seyrig[83] also sees an obstacle in the narrow neck for the possibility of their being hand grenades. It was difficult to fill them with large quantities of powder, and he was not aware if such an experiment had ever been undertaken. M. Mercier, who was in favour of this hypothesis, did not give any indication of a practical experiment of this kind.[84] Moreover, he calls attention to the fact[85] that only in rare cases was incendiary material found in the specimens preserved. A chemical analysis had shown disappointing results in this respect, adds Seyrig.

With regard to his last objections, it must be remarked that he does not seem to have read Mercier's book[86] completely. It also seems that Seyrig to a certain extent contradicts the content of his own footnotes, which are related to this question.

Seyrig also asks us to bear in mind that many grenades are decorated[87] and that some of them carry blessings or messages of congratulation.[88]

The answer of the adherents of the grenade theory «that some people decorate their arrows»[89] failed to convince him.[90] Without repeating his arguments here, we may say that most of the incendiary projectiles depicted in Arabic books on military technology are lavishly decorated, as in those by Ḥasan ar-Rammāḥ (MS Paris) or Aranbuġā az-Zaradkāš (MS Topkapı Sarayı). Among the «three hypotheses» known to him, Seyrig tends to favour that of the aelopiles or wind-balls (*aeolipila*). This steam blower is «a metal ball with a fine opening, which is filled with water and then put into fire in order to show ‹the violent blowing› of the steam».[91] The aelopile was already known to Heron and Vitruvius. In his article of 1951, W. L. Hildburgh[92] wonders whether our vessels of burnt clay could not be a type of aelopile. [104] Then, in 1965, Richard Et-

[78] *Quelques points de l'histoire du pétrole. Vérifications par le laboratoire*, in: IIme Congrès Mondial du Pétrole, Paris 1937, vol. 4, section 5: Économie et statistique, pp. 87-95; idem, *Le feu grégeois*, op. cit., p. 99.

[79] *Le feu grégeois*, op. cit., pp. 123-126.

[80] ibid., pp. 94, 126.

[81] in: Syria. Revue d'art oriental et d'archéologie (Paris) 36/1959/38-89; esp. pp. 81-89: 75. *Flacons? grenades? éolipiles?*

[82] ibid., p. 83.

[83] ibid., p. 85.

[84] ibid., p. 85.

[85] ibid., p. 85.

[86] *Le feu grégeois*, op. cit., pp. 131 – 150, see also the lists of contents of grenades no. 1-8 in Mercier's possession in the appendix of the book.

[87] *Antiquités syriennes*, op. cit., p. 85.

[88] ibid., p. 84.

[89] ibid., p. 85. He is refering here to Fr. Sarre (*Das islamische Milet* by Karl Wulzinger, Paul Wittek, Friedrich Sarre, Berlin and Leipzig 1935, p. 76) who emphasizes «that it is particularly in accordance with the character of Islamic creativity to decorate an object without taking into account whether its decoration will be noticed or not. Often the invisible underside of an instrument of metal is decorated in the same rich style as the visible side.» See also the earlier explanation by Fr. Sarre, *Keramik und andere Kleinfunde der islamischen Zeit von Baalbek*, in: *Baalbek. Ergebnisse der Ausgrabungen und Untersuchungen in den Jahren 1898 bis 1905*, vol. 3, by H. Kohl, D. Krencker, O. Reuther, Fr. Sarre, M. Sobernheim, Berlin and Leipzig 1925, pp. 133-135.

[90] ibid., p. 86.

[91] Franz Maria Feldhaus, *Die Technik. Ein Lexikon der Vorzeit, der geschichtlichen Zeit und der Naturvölker*, Wiesbaden 1914 (reprint Munich 1970), column 26.

[92] *Aelopiles as fire-blowers*, in: Archaeologia (Oxford) 94/1951/27-55; see H. Seyrig, op. cit., p. 89.

tinghausen[93] took up the subject from the point of view of art history. After the «sound objections» from Henri Seyrig, as he says, he himself now began to view with doubts the explanation of the vessels as hand grenades. Among other things, he points to one of the objections raised by Seyrig, namely the appearance of blessings like the *basmala* on the vessels.[94] Among the interpretations known to him, he considers that by E. von Lenz[95] to be the most likely one, although it was not the only possibility.[96] Lenz had opined that the vessels could possibly be containers for quicksilver. However, Ettinghausen does not commit himself to any one interpretation and expresses the hope that the study of manuscripts, chemical examination and aerodynamic trials might bring clarification in future.[97] Unfortunately he does not seem to have known the results of the chemical analyses recorded by M. Mercier. The most recent study on the subject known to me at this moment carries the title *A sphero-conical vessel as fuqqāʿa , or a gourd for «beer»* and is by A. Ghouchani and C. Adle.[98] From this article we learn more than we had known to date about the widespread usage of the word *fuqqāʿa* in Arabic-Persian literature in the sense of a drinking vessel. But the two authors also emphasize quite rightly the possibility that a *fuqqāʿa* can also have served for other purposes.[99] They give photos of a number of vessels with the inscription *išrab hanīʾan* («to your very good health!») and refer to them as sphero-conical vessels characterized by a «thick body, narrow opening, and short neck.» But not all of them have a sphero-conical form and the characteristics mentioned. In my opinion, the authors disregard one of the most important characteristics. The objects which we might consider as grenades are actually tapering to a point at the bottom so that one cannot put them upright without a support. No doubt, vessels of burnt clay designated as *fuqqāʿa* were used for various purposes, depending on the shape and size.[100] Unlike the large specimens which were hurled by machines, the small hand grenades, had a very narrow mouth of about 3 to 5 mm diameter which did not serve for filling the powder, but obviously for inserting the fuse. As we can observe in almost all hand grenades, a groove separates the button-like neck from the bulbous trunk. This leads us to the conclusion about the manner in which such grenades were made. The bulbous lower part was probably made separately in two halves and was joined together only later on. Likewise, the separately burnt upper part with the fuse was probably only joined to the lower part after it was filled with powder. The groove shows the joining of the two parts. Friedrich Sarre[101] has drawn attention to some casting moulds of stone which were found and described in the 1930s; he reproduced a photo of two such moulds (fig.) They were joined to each other with lead plugs. A chemical examination in Berlin had shown that the stone used consisted of chlorite, which «as a consequence of its low hardness can be worked easily» and which is «relatively resistant to heat».

[105] Sarre's opinion that these are casting moulds for the manufacture of hand grenades can hardly be endorsed since the preserved stone forms are meant for the shaping of «richly decorated vase-like vessels». Moreover, because of the lead plugs the forms are not suitable for firing in the oven; it is more likely that these were casting moulds for metal or glass.

«One of the stone forms carries an incised inscription with the name ‹Shech Pasha›».[102] One type of grenade, called *furqāʿa*, is described by the Rasʿlid king al-Muẓaffar Yūsuf b. ʿUmar (d. 694/1294) in his book *al-Muḫtaraʿ fī funūn aṣ-ṣunaʿ*. It consisted of a specially prepared hard cardboard which was

[93] *The uses of sphero-conical vessels in the Muslim East*, in: Journal of Near Eastern Studies (Chicago) 24/1965/218-228.
[94] ibid., p. 225.
[95] *Handgranaten oder Quecksilbergefäße*? In: Zeitschrift für historische Waffenkunde (Dresden) 6/1912-1914/367-376; refutation of W. Gohlke, *Handbrandgeschosse aus Ton*, ibid., pp. 378-387.
[96] R. Ettinghausen, *The use of sphero-conical vessels*, op. cit., p. 224.
[97] ibid, p. 226.
[98] Published in Muqarnas. An annual on Islamic art and architecture (Leiden) 9/1992/72-92; see also Edward J. Keall, «*One man's Mede is another man's Persian; one man's coconut is another man's grenade*», in: Muqarnas 10/1993/275-285.
[99] *A sphero-conical vessel*, op. cit., pp. 73,76.
[100] Emily Savage-Smith also makes this assumption in her attempt to provide a typology of such vessels and in her description of those in the Khalili collection. She rules out the possibility of grenades. See *Sphero-conical vessels: a typology of forms and functions*, in: *Science, Tools and Magic*. Part Two: *Mundane Worlds*, Oxford 1997 (The Nasser D. Khalili Collection of Islamic Art, vol. 12, part 2), pp. 324-337.
[101] *Das islamische Milet*, op. cit., pp. 77-78.
[102] At this point I should like to thank Mrs. Gisela Helmecke (Museum für islamische Kunst, Berlin) for her valuable explanations.

filled with gunpowder and provided with a fuse.[103] Finally we may refer to an informative passage in the book by Ḥasan ar-Rammāḥ (MS Paris, Bibl. Nat. 2825) to which E. Quatremère[104] drew attention more than 150 years ago. In connection with the use of gunpowder (*bārūd*), the author speaks of «pitchers» (*kīzān fuqqāʿ*) that were «fastened to the tips of lances» (*murakkaba ʿalā ruʾūs ar-rimāḥ*). Thus we learn that, when necessary, grenades (after ignition) were also fastened to lances and hurled at the enemy.

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[103] Ed. M. ʿĪ. Ṣāliḥīya, Kuwait 1989, pp. 206-207.

[104] *Observations sur le feu grégeois*, in: Journal Asiatique, sér. 4, 15/1850/214-274, esp. p. 246.

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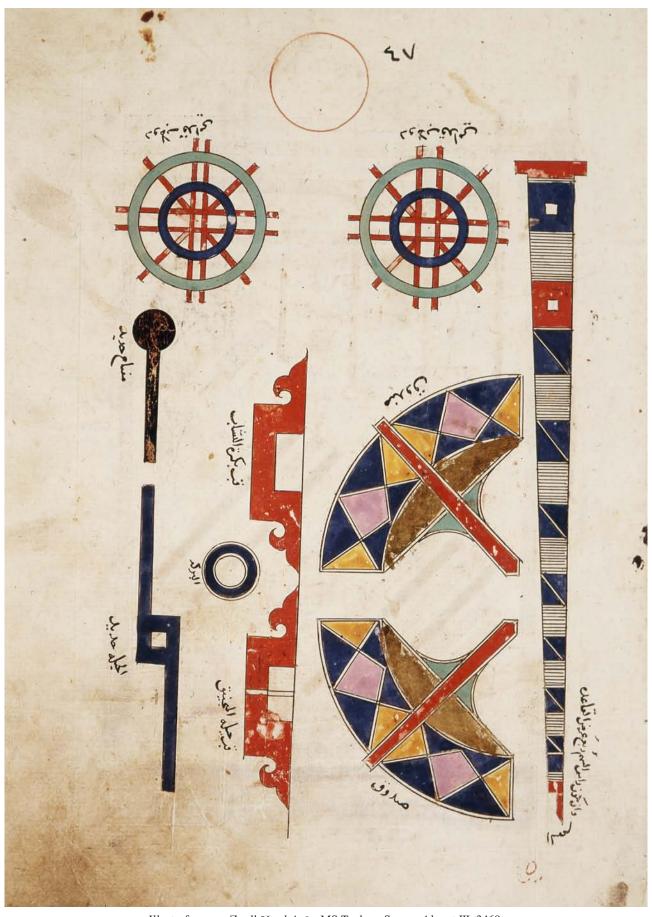

[1] At this point I should like to thank Mrs. Gisela Helmecke (Museum für islamische Kunst, Berlin) for her valuable explanations.

[2] Ed. M. ʿĪ. Ṣāliḥīya, Kuwait 1989, pp. 206-207.

[3] *Observations sur le feu grégeois*, in: Journal Asiatique, sér. 4, 15/1850/214-274, esp. p. 246.

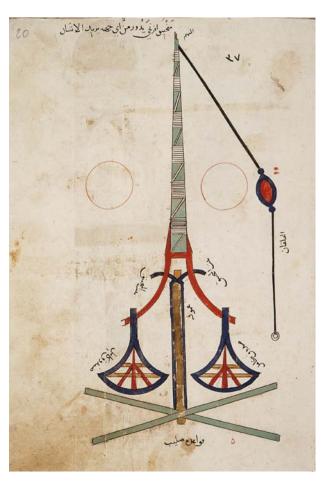
Illustr. from: az-Zardkāš, *al-Anīq*, MS Topkapı Sarayı, Ahmet III, 3469.

Traction
Trebuchet

Our model:
Wood and steel.
Length of the ejector arm: 82 cm.
(Inventory No. G 1.01)

The traction trebuchet is designated as the «King's trebuchet» (*manǧanīq sulṭānī*) by az-Zaradkāš (ca. 775/1374).[1] Here the required leverage is provided by human power.[2] In our illustration the instrument was constructed in such a way that it was to be operated by ten soldiers. They tautened the ejector arm by pulling on the ropes fastened to rings on the right and on the left.[3]

Illustration from:
az-Zardkāš,
al-Anīq, MS Topkapı
Sarayı, Ahmet III, 3469.

[1] *al-Anīq fi l-manāǧnīq*, ed. I. Hindi, Aleppo 1985, pp. 100-102.
[2] G. Köhler, *Die Entwickelung des Kriegswesens*, op. cit., p. 164 ff.; K. Huuri, *Zur Geschichte des mittelalterlichen Geschützwesens*, op. cit., p. 171.
[3] A. al-Hasan, D. R. Hill, *Islamic Technology*, op. cit., p. 100.

Our model:
Wood and steel.
Length of the ejector arm: 70 cm.
(Inventory No. G 1.02)

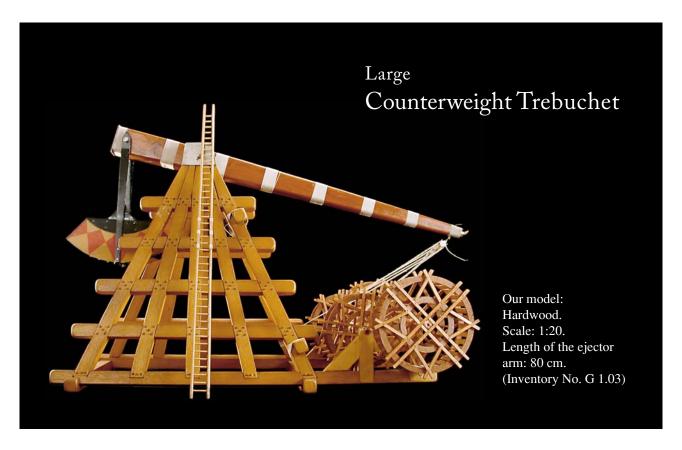
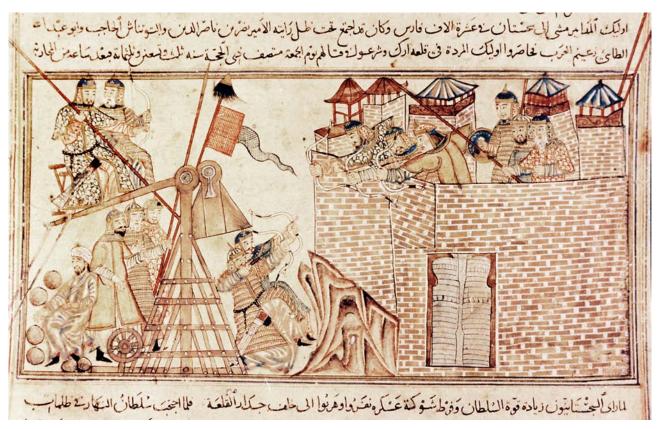
Counterweight
Trebuchet

Az-Zaradkāš (ca. 775/1374) knows a particular form of the trebuchet called the «European catapult» (manǧanīq ifranǧī). Obviously here it has to do with the counterweight trebuchet (trebuchium) which the «Franks» used. We may assume that this type of catapult was known as early as the first half of the 13th century in Europe.[1] Az-Zaradkāš mentions that a special feature here is that it can be moved easily to any direction.[2] Two wooden boxes filled with stones produce the counterweight, while the ejecting momentum remains constant.

Illustration from:
az-Zardkāš, *al-Anīq*, MS Tokapı Sarayı, Ahmet III, 3469, p. 37.

[1] K. Huuri, *Zur Geschichte des mittelalterlichen Geschützwesens*, op. cit., pp. 64-65.
[2] *al-Anīq fi l-manāǧnīq*, op. cit., pp. 97-99.

Large
Counterweight Trebuchet

Our model:
Hardwood.
Scale: 1:20.
Length of the ejector arm: 80 cm.
(Inventory No. G 1.03)

The large catapult, called *qarābuġā* («black bull»), seems to be the highest stage of development of trebuchets which were gradually superseded by cannons from the 9th/15th century onwards. The characteristic features which distinguish it from its equally large predecessors are the use of force produced by the tread-wheel and block and tackle, the use of the protractor for taking aim and the use of a surveyor's levelling instrument when setting it up. Az-Zaradkāš[1] describes the function and use of this trebuchet and provides quite precise illustrations of its component parts. He also mentions another type of this large catapult which was called *manǧanīq az-ziyār* (see below, p. 110) and which was apparently quite widespread in the 7th/13th century in the Islamic world.

The trebuchet consists mainly of two supporting frames between which a horizontal beam, i.e. the axis of rotation, is fastened. Around this axis an

Illustration from: az-Zardkāš, *al-Anīq*, MS Ahmet III, 3469.

[1] *al-Anīq fi l-manāǧnīq*, op. cit., pp. 66-68.

Scene of siege from the World History (*Ǧāmiʿ at-tawārīḫ*) by Rašīdaddīn Faḍlallāh, MS Edinburgh University Library, Or. 20, fol. 124 b. The manuscript was copied and illustrated in 707/1306 during the author's lifetime.

Illustration from: *K. al-Furūsīya fī rasm al-ǧihād* by Ḥasan ar-Rammāḥ (m. 694/1295), Paris, Bibliothèque nationale, ar. 2825.

ejector arm can swing which is divided by the axis of rotation [109] into two parts of unequal length. A wooden box filled with stones is attached to the short end of the ejector arm; the end of the longer arm of the lever has a leather sling for receiving a stone or another kind of projectile. When the long lever arm is pulled downwards by means of ropes, windlasses and tread-wheels, the short arm with the counterweight goes up at the same time and keeps the long arm, which is anchored with a hook, under tension. Then after the projectile has been put in position and the hook released, the counterweight pulls the short arm downwards, the long arm leaps high at the same time and hurls the load, mostly stones or incendiary projectiles, in a high arc towards the target.

Our model:
Hard wood; Scale 1:20.
59 × 85 cm.
(Inventory No. G 1.20)

Counterweight Trebuchet
with Arrow Ejector

This type of trebuchet was a sub-variety of the *qarābuġā* already mentioned and was called *az-ziyār* in Arabic. The main difference between the two was that the latter was meant to hurl heavy arrows instead of stones or other voluminous objects. For this purpose the container which served as counterweight and which was filled with stones was replaced by a massive piece of iron. The arrows had flipper-like stabilizers at the end of the shaft. They were shaped in such a way that they could be pulled into a groove at the base of the trebuchet by means of a suitable hook on a rope that was fastened to the ejector arm. Apparently the slope of the groove used to be regulated according to the target. We may assume what [111] az-Zaradkāš, the author of

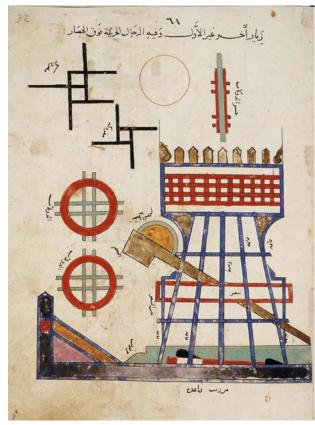



Illustration from: az-Zardkāš, *al-Anīq*, MS Ahmet III, 3469, p. 61.

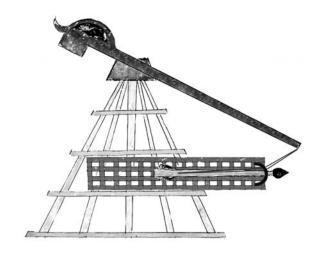



Illustration from:
az-Zardkāš, *al-Anīq*, MS Topkapı Sarayı, Ahmet III, 3469, p. 65.

the K. *al-Anīq fi l-manāğnīq*,[1] leaves unmentioned, namely, that at the front of the groove a suitable guideway was fastened, perhaps in the form of a bridge, so that the arrow was not pulled too far in the vertical direction.
The direction of the shot of this trebuchet was staggered by 180° compared to that of the other type of large trebuchet.
We do not know at present from when the increased momentum of the counterweight trebuchet began to be employed in the Islamic world for shooting arrows and other projectiles. From the statements in the *Tabṣirat arbāb al-albāb* by Marḍī aṭ-Ṭarsūsī (6th/12th c.), it is obvious (see below, p. 121 ff.) that this combination was even known at the time of Ṣalāḥaddīn (Saladin).

Attempt at a reconstruction of the arrow launching ramp with guideway (montage).

[1] *al-Anīq fi l-manāğnīq*, op. cit., pp. 92-96.

Counterweight Trebuchet
with Cross Bow

Our model:
Wood and laminating material
100 × 45 × 54 cm.
(Inventory No G 1.19)

This war engine is one of those described by the above-mentioned (see above, p. 94) Marḍī b. ʿAlī aṭ-Ṭarsūsī (6th/12th c.) in his book *Tabṣirat arbāb al-albāb fī kaifīyat an-naǧāt*[1] dedicated to the ruler Ṣalāḥaddīn (Saladin). He calls it «Persian counterweight trebuchet» (*manǧanīq fārisī*) and says that master Abu l-Ḥasan al-Abraqī al-Iskandarānī had described and drawn the device for him.
Here the windlass is replaced by a double block and tackle. The force needed for lifting the counterweight and for tautening the bow is transmitted by the block and tackle and by the sufficiently long arm of the trebuchet. The trigger simultaneously releases the stone projectile for hurling and the crossbow for shooting.

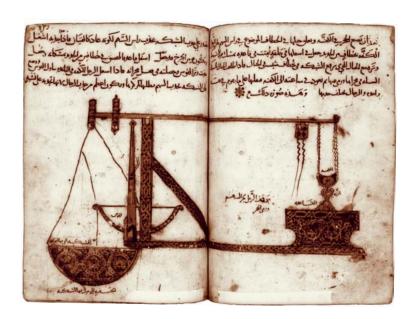
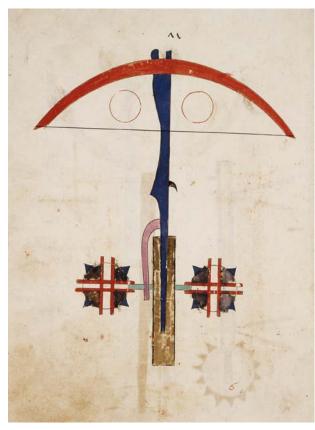



Illustration from: Marḍī, *Tabṣira,* MS Oxford, Hunt. 264, fol. 129b et 130a.

[1] MS Oxford, Bodleian Library, Hunt. 264 (fol. 133b-136b), see Cl. Cahen, Un traité d'armurerie, op. cit., pp. 119-120 and plate III, No. 14.

Windlass Crossbow

Our model:
Wood, metal. 110 × 80 cm.
String made of elastic rope for demonstration purposes.
(Inventory No. G 1.17)

This type of crossbow, in Arabic *qaus bi-l-laulab*, which is tautened by one or several windlasses (rack-and-pinion gear), was popular as early as the 5th/11th century in the Arab-Islamic world (see above, p. 94). In the 6th/12th century it was described in detail by Marḍī b. ʿAlī aṭ-Ṭarsūsī in his book on military technology (*Tabṣirat arbāb al-albāb fī kaifīyat an-naǧāt*) dedicated to the ruler Ṣalāḥaddīn (Saladin). In our model we mainly followed the illustration provided in the *al-Anīq fi l-manāǧniq* of the 8th/14th century.

Illustration from:
al-Anīq fi l-manāǧnīq.

Illustration from:
Marḍī, *Tabṣira,* MS Oxford, Hunt. 264, fol. 112b.
The view from above seems to include the walls of the tower where this large crossbow is installed.

Our model:
Wood, reed, brass, string.
55 × 45 cm.
(Inventory No. G 1.18)

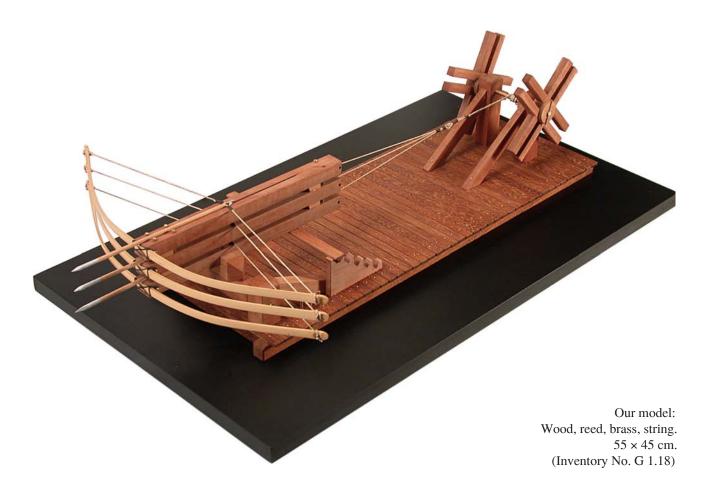
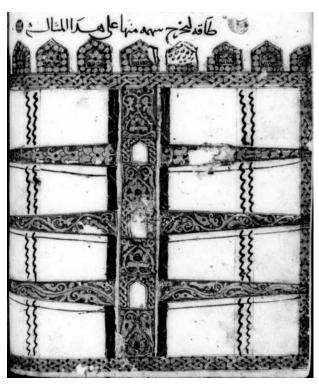
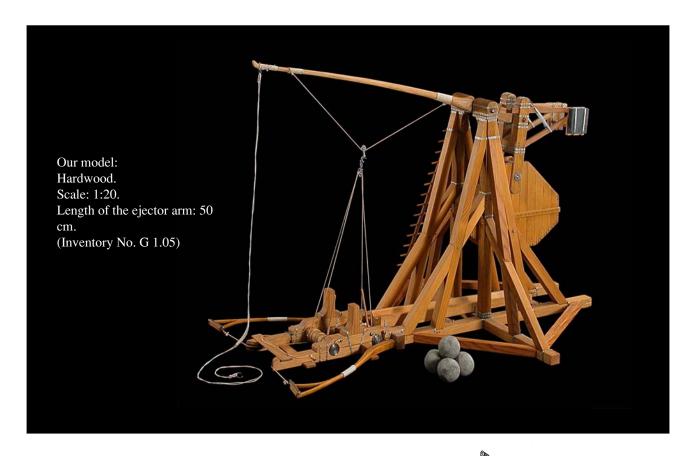
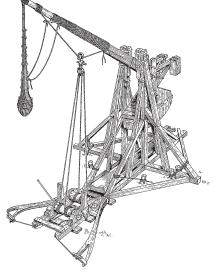



Illustration from: Marḍī, *Tabṣira,*
MS Oxford, Bodl., Hunt. 264.

Large
triple Crossbow
(Ballista)

Among the various types of crossbows described by Marḍī aṭ-Ṭarsūsī (6th/12th c., see above, p. 94) in his book *Tabṣirat arbāb al-albāb*,[1] the most elaborate one consists of three large rampart crossbows (*qaus az-ziyār bi-l-laulab*) which could be installed one above the other and tautened with one single windlass and could therefore be operated by a single person alone.
Our model is simplified.

[1] MS Oxford, fol. 80 b; transl. by Cl. Cahen, op. cit., p. 131.

Arab Counterweight Trebuchets in Occidental tradition

The advanced form of the catapult, as compared to its predecessor (onager) known from Roman times, which was developed in the Arab-Islamic world, can be shown to have existed since the 6th/12th century on the basis of descriptions, illustrations and citations in sources; and it seems to have been known in the West at the latest in the first half of the 13th century (see above, p. 108). For comparison with the Arabic predecessors there are four models of occidental trebuchets in the Museum of the Institute for the History of Arab-Islamic Sciences; these were prepared by Werner Freudemann around 1990.

Our model:
Hardwood.
Scale: 1:20.
Length of the ejector arm: 50 cm.
(Inventory No. G 1.05)

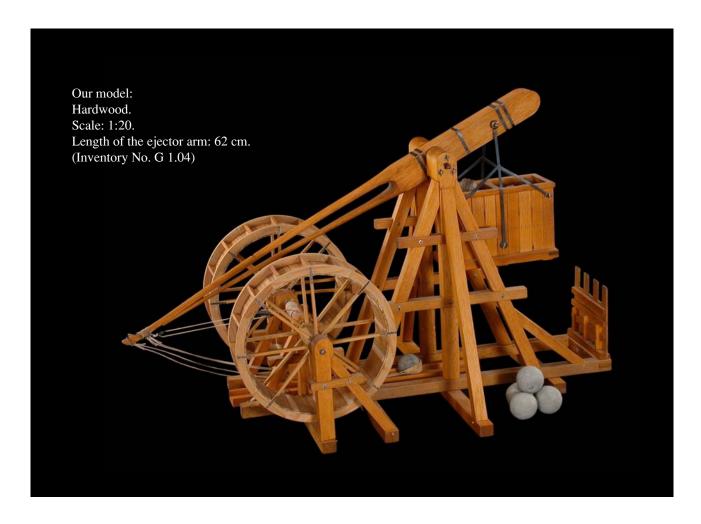
1.

A trebuchet reconstructed according to the information given by Villard de Honnecourt (1st half of the 13th c., see above, p. 60). The often published reconstruction sketch by Eugène Emmanuel Viollet le Duc (1814-1879)[1] turned out to be unreliable. Our model was built by W. Freudemann according to improved technical data.

Illustration from:
R. A. Brown,
Castles. A History and Guide, Dorset 1980, p. 81.

[1] Reproduced, for example, in Rüstungen und Kriegsgerät im Mittelalter by Liliane and Fred Funcken, Gütersloh 1985, p. 54.

Our model:
Hardwood.
Scale: 1:20.
Length of the ejector arm: 62 cm.
(Inventory No. G 1.04)

2.

European trebuchet of ca. 1405, constructed on the basis of an illustration in Bellifortis[1] by Konrad Kyeser of Eichstätt (completed 1405). W. Freudemann improved the model as against the illustration, in order to make it functional.[2]

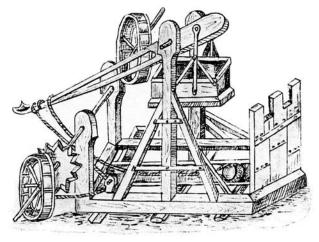
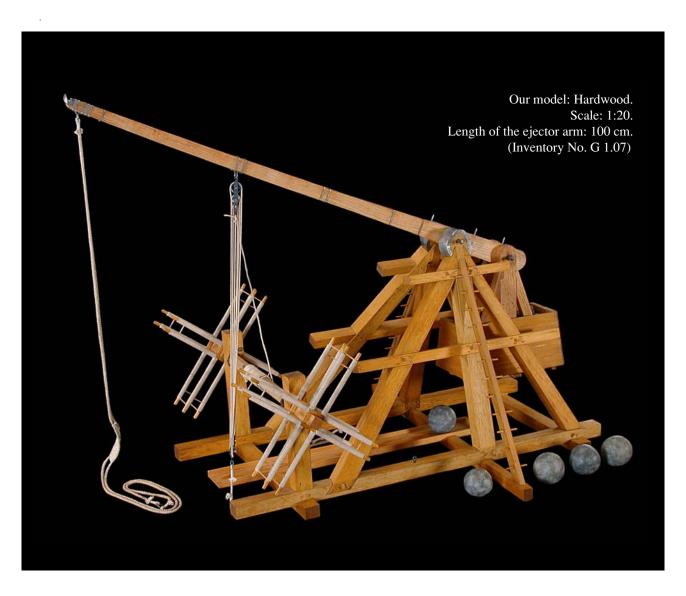
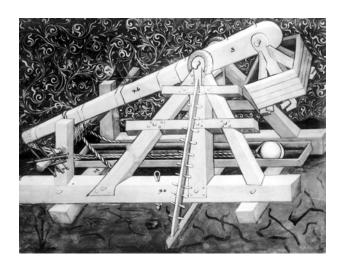



Illustration from: Kyeser, *Bellifortis* (Göttingen, Univ. Bibl., Cod. MS philos. 63, fol. 48a) after W. Gohlke, *Das Geschützwesen des Altertums und des Mittelalters*, in: Zeitschrift für Historische Waffenkunde V, 12 (Dresden 1909–1911) p. 385, illustr. 41.

[1] Ed. by Götz Quarg, Düsseldorf 1967 (see Hermann Heimpel, review in: Göttingische Gelehrte Anzeigen 223/1971/115-148); V. Schmidtchen, *Mittelalterliche Kriegsmaschinen*, Soest 1983, pp. 123, 192.
[2] Freudemann points out that a model built strictly according to the illustration could not work, because first «The connecting piece above the chute, which terminates at the left extremity of the guide beam would make the procedure of ejection impossible.» And secondly, «The catapult is much too long. The ropes of the catapult do not run freely under the windlass shaft». Furthermore, he added necessary details and «adjusted» the proportions, particularly those of the tread-wheels.

Our model: Hardwood.
Scale: 1:20.
Length of the ejector arm: 100 cm.
(Inventory No. G 1.07)

3.

One more European trebuchet of ca. 1405. It is also depicted and provided with measurements in Bellifortis (MS Göttingen, fol. 30) by Konrad Kyeser of Eichstätt and was reconstructed around 1990 by W. Freudemann. Moreover, it is of special interest here that the releasing mechanism is clearly discernable in the illustration and could be reconstructed exactly.

Illustration from:
Kyeser, *Bellifortis,* Göttingen, Univ. Bibl.,
Cod. MS philos. 63, fol. 30a.

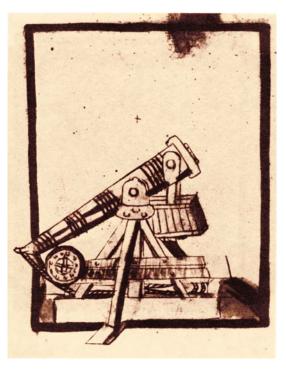



Illustration from MS Vienna, Cpv 3069, after Schmidtchen, *Mittelalterliche Kriegsmaschinen*, op. cit., p. 18

Our model: Hardwood. Scale: 1:20.
Length of the ejector arm: 100 cm.
(Inventory No. G 1.07)

4.

European trebuchet, constructed by W. Freudemann on the basis of the following models: Konrad Kyeser, Bellifortis (MS fol. 30 and 77) and one drawing each from Cod. germ. 600, Bayerische Staatsbibliothek, Munich (ca. 1390)[1] and manuscript Cpv 3069 in Vienna.[2]

Illustration from: Cod. germ. 600, Bayerische Staatsbibliothek Munich (ca 1390).

[1] Bernhard Rathgen, *Das Geschütz im Mittelalter*, Berlin 1928 (repr. Düsseldorf 1957), pp. 626–627, 719, fig. 2.

[2] V. Schmidtchen, op. cit., p. 189, fig. 58.

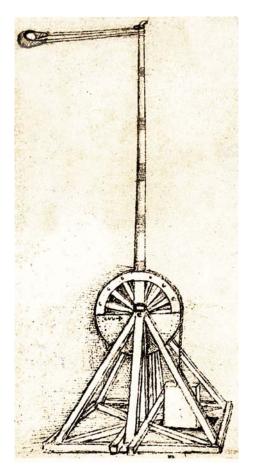
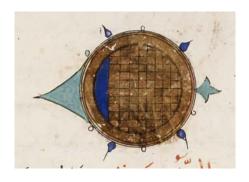



Illustration from: *Leonardo da Vinci*, p. 294.

Trebuchet
with distance regulator

Our model:
Wood, metal, yarn.
Height with vertical ejector arm: 1.17 metres.
(Inventory No. G 1.21)

The drawing of this trebuchet by Leonardo da Vinci has already been discussed above (p. 98). Our model is based on it. It may be recalled here that a distance regulator is used with this piece of artillery as we know it from Arab models at the latest since the 8th/14th century (see below, p. 134). Some progress can be seen here in that the distance regulator in the form of a wheel is attached to the trebuchet.

Illustr. extraites de: az-Zardkāš, *al-Anīq*, MS Topkapı Sarayı, Ahmet III, 3469.

Our models:
Earthenware, slicker painting
a) ∅ 19 cm. (Inventory No. G 2.18).
b) ∅ 18.5 cm. (Inventory No. G 2.19).

Fire-pot
and ‹biological› grenade

A fire-pot (*qidr*) with rim, filled with a mixture containing saltpetre, was built primarily for the purpose of explosive effect. It has three small tubes (*ikrīḫ*) filled with a mixture of incendiary substances and is hurled after ignition from a trebuchet or by means of a lance.[1]

Model b) represents an early form of the ‹B-weapon›, a grenade filled with dangerous animals like scorpions or snakes, which is characterized by numerous small air holes.

[1] Reinaud and Favé, *Du feu grégeois*, op. cit., p. 44; illustrations section, plate II, fig. 23; S. J. von Romocki, *Geschichte der Explosivstoffe*. I. *Geschichte der Sprengstoffchemie, der Sprengtechnik und des Torpedowesens bis zum Beginn der neuesten Zeit*, Berlin 1895, pp. 71–72.

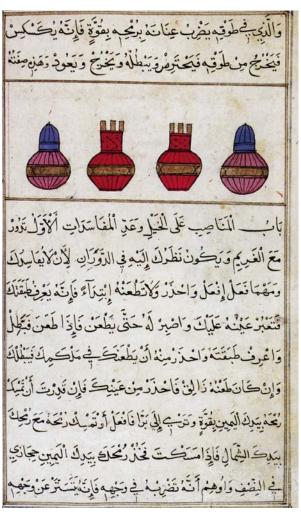



Illustration from: az-Zardkāš, *al-Anīq*, MS Topkapı Sarayı, Ahmet III, 3469.

Illustration of *qawārīr* (sing. *qārūra*, ‹pot›): *al-karrāz al-ʿirāqī* (‹Iraki pot›) and *al-karrāz aš-šāmī* (‹Syrian pot›) from Ḥasan ar-Rammāḥ, *K. al-Furūsīya*, MS Paris, Bibl. nat., ar. 2825, fol. 88.

Illustration from: *al-Maḫzūn fī ǧāmiʿ al-funūn*, MS Leningrad, C686, fol. 146.

Our models:
Earthenware, brown engobe, wick.
Height 17-19.5 cm.
(Inventory No. G 2.03-06)

Grenades

All illustrations from the *Khalili Collection*, op. cit., vol. 12.2, pp. 324, 334 ff.

Our models:
Earthenware, brown engobe, fuse.
Height: 10-16 cm.
(Inventory No. G 2.11 -17)

Illustration of warships with incendiary and/or blasting mixture,
from Ḥasan ar-Rammāḥ, *K. al-Furūsīya*,
MS Paris, Bibl. Nat., ar. 2825, fol. 100.

Flame-thrower

(*ṣandūq muḥāsafa*)

Our model:
Copper, soldered. Length: 30 cm.
(Inventory No. G 2.22)

In the Kitāb *al-Anīq fi l-manāğnīq* by Ibn Aranbuġā az-Zaradkāš[1] (774/1373) a flame-thrower (*ṣandūq [al-]muḥāsafa)* is described which was used in close combat and which could produce a flame the length of a lance. It consists of a longish reservoir of metal for paraffin which is connected through two tubes with a cylindrical nozzle. From this the incendiary material is sprayed with a pump while it is lit by a small igniter.

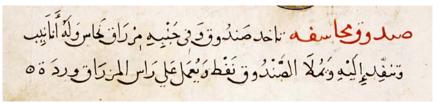



Illustration from az-Zardkāš, *K. al-Anīq*,
MS Topkapı Sarayı, Ahmet III, 3469, p. 99.

[1] MS op. cit., p. 98–99; A.Y. Hassan, D.R. Hill, *Islamic Technology*, op. cit., p. 108.

Our model:
Copper, soldered. Length 36 cm.
(Inventory No. G 2.07)

aṭ-ṭaiyār al-maǧnūn

(Torpedo or rocket)

Illustration from Ḥasan ar-Rammāḥ, *K. al-Furūsīya,* MS Paris, Bibl. nat., ar. 2825, fol. 101 b.

In the course of his discussion of rockets and projectiles which function with rocket propulsion elements of saltpetre, sulphur and coal, Naǧmaddīn Ḥasan ar-Rammāḥ,[1] the famous tournament master of the Mameluk period (d. 694/1295), describes «a device which he calls ‹moving and burning egg›. It is also depicted in the copy illustrated. The text and the illustration (see ill.), particularly when combined with Occidental data which will be provided later, leave no doubt that this is a self-moving torpedo which, though primitive, is fully developed in all the essentials.»

«Two concave sheets of iron… are joined together and made tight with felt so that they form a flattened pear-shaped hollow body (…) which is loaded with ‹naphthalene, metal filings and good mixtures … by the latter phrase Hassan always refers to mixtures having a high content of saltpetreȘand is

[1] *Kitāb al-Furūsīya wa-l-manāṣib al-ḥarbīya*, MS Paris, Bibl. Nat., ar. 2825, fol. 101b; Reinaud and Favé, *Du feu grégeois*, op. cit., p. 45, illustrations section, plate II, fig. 32.

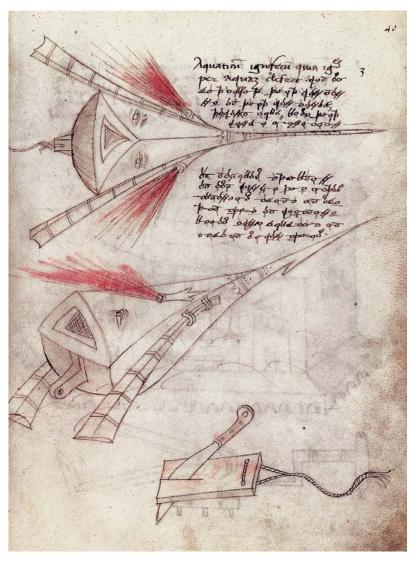



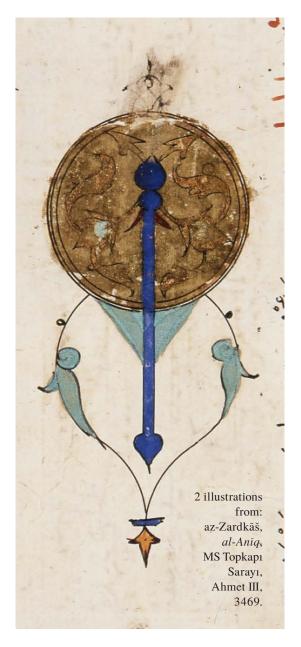
Illustration from Fontana, *Le macchine cifrate*, p. 126.

provided with two rods (…) and a large rocket (…). In his text Hassan does not say in which element [126] ‹the moving and burning egg› is supposed to move; but one glance at the illustration should suffice to show the device could have been destined neither for flying, as Reinaud and Favé hoped, nor for sliding forward, not even on the most favourable terrain …»[2]

In this connection, it is intriguing to note that a fairly simple description of a rocket-torpedo is to be found in Bellifortis by Konrad Kyeser (1405).[3] Even more remarkable seems to be the fact that torpedoes with rockets appear in *Bellicorum instrumentorum liber* by Giovanni Fontana (1st half of the 15th c.).[4]

Towards the end of the 19th century S. J. von Romocki[5] expressed the view that Fontana followed Ḥasan ar-Rammāḥ in this matter. In our view, it need not necessarily have been Ḥasan ar-Rammāḥ's book which formed Fontana's source. His book is merely the closest work on the subject known to us at this time which we can use for comparison. There cannot be any doubt about the fact that in the Arab-Islamic world numerous treatises were written on warfare and weaponry, some of which reached Europe, particularly during the Crusades. Moreover, the influence of Arab-Islamic culture on Fontana and other European scholars in respect of weaponry and other technological achievements did not come about by books alone. The Crusades undoubtedly played an important role in this connection.

Cf. also Reinaud and Favé, Du feu grégeois, op. cit., pp. 311-313.

[2] S. J. von Romocki, *Geschichte der Sprengstoffchemie*, op. cit., pp. 70–71; A.Y. al–Hassan and D. R. Hill, *Islamic Technology*, op. cit., p. 118; J. R. Partington, *A History of Greek Fire and Gunpowder*, op. cit., p. 203.

[3] Cf. Romocki, op. cit., p. 153, where the author, instead of thinking of a dependence on the Arab–Islamic world, concludes: «Here we have the prototype of the rocket–torpedo which is already improved by Hassan Alrammah. But here also the description obviously rests on an actual experiment and not merely on a plan; because theoretically the author could hardly have found that a much shorter rod was sufficient to keep a rocket in a straight direction on water than to achieve the same result in air.»

[4] E. Battisti and G. Saccaro Battisti, *Le macchine cifrate di Giovanni Fontana*, Milan 1984, p. 126.

[5] Romocki, *Geschichte der Sprengstoffchemie*, op. cit., p. 230, 236, 240.

2 illustrations from: az-Zardkāš, *al-Anīq*, MS Topkapı Sarayı, Ahmet III, 3469.

Our model: Copper, soldered. Length: 55 cm. (Inventory No. G 1.12)

Grenades

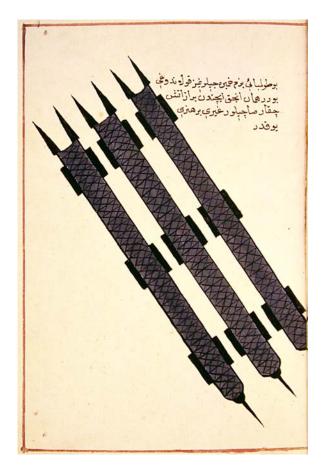
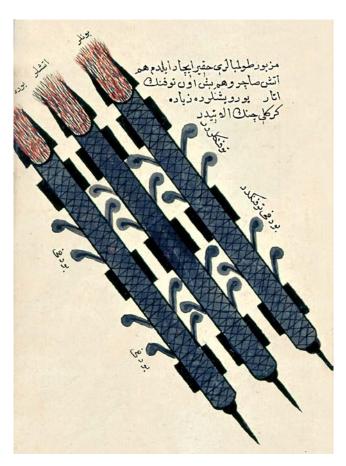
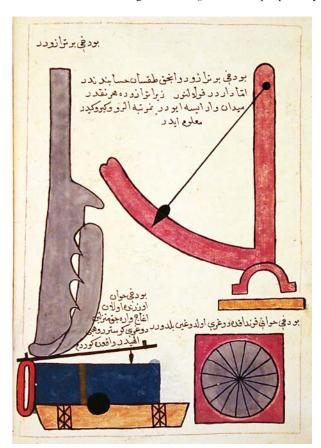
with chemical war materials

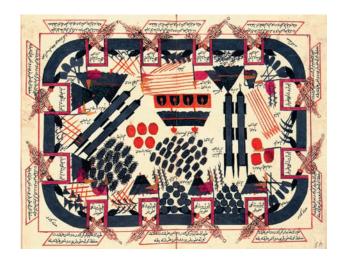
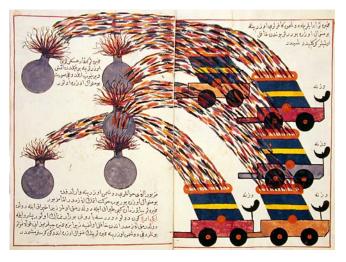
In the Kitāb *al-Anīq fi l-manāǧnīq*[1] (8th/14th c.) the content of a «pot» (*qidr*) is described, which is put together from various substances, among them opium and arsenic; here «pot» is used in the sense of a bomb or grenade, and the substances are said to have a suffocating effect on the adversary. The bomb was called *al-qidr al-muntin li-l-muḫāsafa*.[2] It was probably hurled from trebuchets, shot with a crossbow or thrown by hand, as the occasion demanded.[3]

[1] Ed. Aleppo, op. cit., p. 174.
[2] in the manuscript *qidr muntin al-muḫāsafa*.
[3] Ḥasan ar-Rammāḥ's book also contains «instructions for the manufacture of poisonous and soporific vapours, the effective contents of which are arsenic and opium» (v. Ḥasan ar-Rammāḥ, *al-Furʿsīya wa-l-manāṣib al-ḥarbīya*, op. cit., pp. 141, 156, 161, 162, 163; Romocki, *Geschichte der Sprengstoffchemie*, op. cit., p. 74).

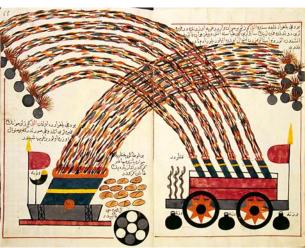
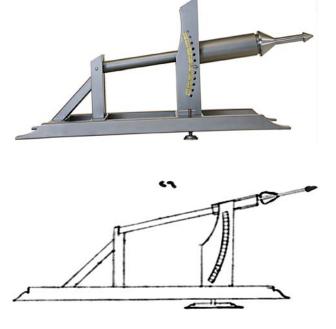
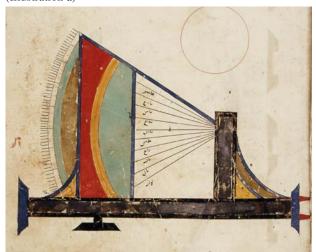
Both our models:
Copper, soldered.
Length: 67 cm.
(Inventory No. G 1.13)

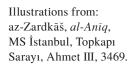
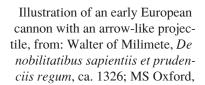
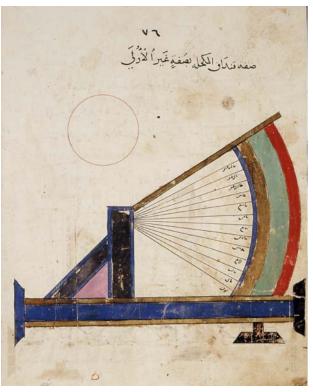
Ottoman
Rockets

The Ottoman engineer Lāgarī Ḥasan Çelebī, under Sultan Murād IV (ruled 1032/1623-1049/1640, was certainly following the Arab-Islamic tradition when he built a rocket with seven small side-fins. The fuel of the rocket is said to have consisted of ca. 50 okkas (ca. 60 kg) of gunpowder. As reported by the contemporary Turkish historian Evliyā Çelebī,[1] Ḥasan Çelebī is said to have demonstrated to the Sultan that he could fly across the Bosporus with his rocket and that he could land with the help of additional wings. What is interesting in this connection is the fact that Ogier Ghislain de Busbecq, who was the Habsburg envoy in Istanbul between 1555 and 1562, reports about attempts at flying under Sultan Süleymān (‹the Magnificent›, ruled 926/1520-974/1566), as John Wilkins (1638) informs us.[2]
Detailed information about Ottoman rockets with interesting illustrations is given in his book *Umm al-ġazā*[3] by the engineer ʿAlī Āġā, who was active under Sultan Aḥmed III (ruled 1115/1703-1143/1730). The length of the rockets built by ʿAlī Āġā is said to have been 7-8 metres. About their circumference he says that a man could hardly encircle them with his arms.
Since this book was hardly known before now, it seemed appropriate to add a few more illustrations which are of interest for military history and the history of technology.

[1] *Seyâhatnâme*, Istanbul 1969, vol. 2, pp. 335-336; Arslan Terzioğlu, *Türk-islâm kültür çevresinde IX. yy'dan XVIII. yy.* sonuna kadar uçma denemeleri ve tekniğe ait elyazma eserler, in: İlim ve sanat (Istanbul) 8/1986/54-63, esp. 61-62; idem, *Handschriften aus dem Gebiet der Technik und Aerodynamik sowie der ersten Flugversuche im IX.-XVII. Jhd. im islamisch-türkischen Kulturbereich*, in: Istorija aviacionnoj, raketnoj i kosmiceskoj nauki i techniki, Moscow 1974, pp. 246-256, esp. pp. 253-255; Mustafa Kaçar in: İslâm Ansiklopedisi (Istanbul: Türkiye Diyanet Vakfı), vol. 16, 1997, pp. 315-316.

[2] John Wilkins, *Discovery of a New World*, London 1638 (not seen, v. H. K. Cook, *The Birth of Flight*, London 1941, p. 29, v. A. Terzioğlu, op. cit.).

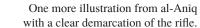
[3] Manuscript İstanbul, Topkapı Sarayı, Bağdat Köşkü nº 368.

Illustrations from: ʿAlī Āġā, *Umm al-ġazā*, MS Topkapı Sarayı, Bağdat Köşkü nº 368.

Illustrations from: ʿAlī Āġā, *Umm al-ġazā*, MS Topkapı Sarayı, Bağdat Köşkü nº 368.

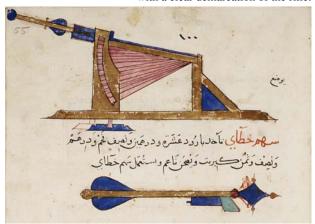
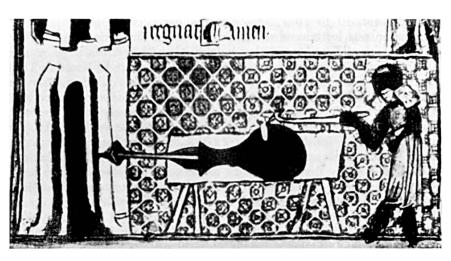
Our model:
Stainless steel, height: 30 cm.
Barrel height adjustable.
Projectile, length 17 cm.
(Inventory No. G 1.16)

Cannon

In the book *al-Anīq fi l-manāǧnīq* (8th/14th c.) a cannon with its components is depicted. It belongs to a stage of development which we can follow in the Arab-Islamic world up to the second half of the 7th/13th century (see above, p. 100). The cannon was called *midfaʿ* or *mikḥala*. The book *al-Anīq* shows three types which differ from one another in the graduations in their scales of distance. The scale of the first type has a division into eleven (illustration a), that of the second a division into fourteen (illustration b) and that of the third a division into ten, which is once again sub-divided (illustration c). The graduated mechanism for taking aim is called *qundāq*, a Turkish word which is still used today in the sense of the firing mechanism of firearms. In the brief description it is pointed out that the firing range increases in ascending order.

One more view of our model when loaded and a sketch from the *al-Anīq*.

(Illustration a)

(Illustration b)

One more illustration from al-Anīq with a clear demarcation of the rifle.

(Illustration c)

Illustrations from: az-Zardkāš, *al-Anīq*, MS İstanbul, Topkapı Sarayı, Ahmet III, 3469.

Illustration of an early European cannon with an arrow-like projectile, from: Walter of Milimete, *De nobilitatibus sapientiis et prudenciis regum*, ca. 1326; MS Oxford,

Hand firearm

Our model:
Steel, length: 81 cm.
(Inventory No. G 2.21)

The oldest description of a hand firearm known to us at present is to be found in the above-mentioned (p. 100) Petersburg manuscript. The French translation by Reinaud and Favé of 1849 was, unfortunately, not taken note of in an appropriate manner by the historiography of the technology of weapons. As far as I can see, O. Baarmann is a notable exception in this regard: «The oldest oriental weapons which operated with the chemical mixture of fireworks, namely the fire lance and the madfaa, can be called the precursors of the firearms which spread more and more in Europe in the second quarter of the 14th century; these were pieces of equipment of the simplest kind which were provided with handles for easy handling. For many decades this method of making firearms suitable for handling remained the only kind and still survived for a very long time next to the others which were just developing. Illustration 1 (after the Arabic manuscript from the beginning of the 14th century in the Asiatic Museum in Petersburg,) shows the handling of the last-mentioned short, wooden, mortar-like weapon.» However, Baarmann regards the illustration erroneously as a mortar-like hand firearm, whereas the illustration in the manuscript refers to a cannon; Baarmann was probably inṭuenced by the poor drawing and he does not elaborate the details of the «fire lance» described there. Here it is a case of a combined hand firearm. In the farther end of a lance sufficient space is hollowed out so that a charge of gunpowder can be placed there. The projectile has the form of an arrow or a bolt. The lance is hollowed out from ca. 10 cm from its farther end up to the tip. This and other details of the text made it possible for us to reconstruct the model above.

Illustration from: *al-Maḫzūn fī ǧāmiʿ al-funūn,* MS Leningrad C686, fol. 156.

The illustration of a «fire barrel» preserved from the 15th century, which was in the possession of Robert Forrer in Germany at the beginning of the previous century is reminiscent of this oldest hand firearm from the Arab-Islamic world.[2]

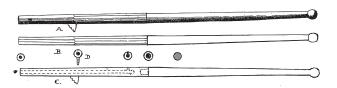



Illustration from Forrer, p. 26.

[1] *Die Entwicklung der Geschützlafette bis zum Beginn des 16. Jahrhunderts und ihre Beziehungen zu der des Gewehrschaftes*, dans: *Beiträge zur Geschichte der Handfeuerwaffen*. Festschrift zum achtzigsten Geburtstag von Moritz Thierbach, Dresden 1905, pp. 54–86, esp. p. 55.

[2] *Meine gotischen Handfeuerrohre*, dans: *Beiträge zur Geschichte der Handfeuerwaffen*. Festschrift zum achtzigsten Geburtstag von Moritz Thierbach, Dresden 1905, pp. 23–31. Cf. also Reinaud and Favé, *Du feu grégeois*, pp. 311–313.

ballistic Gauge

Our model:
Wood, stained and
Brass, etched.
Length: 40 cm.
(Inventory No. G 1.14)

The book *al-Anīq fi l-manāǧnīq*[1] (8th/14th c.) contains the earliest known illustration of a ballistic gauge. Such a device, which was called *mīzān al-qarīb wa-l-ba'id*, was used for the adjustment while taking aim with counterweight trebuchets.

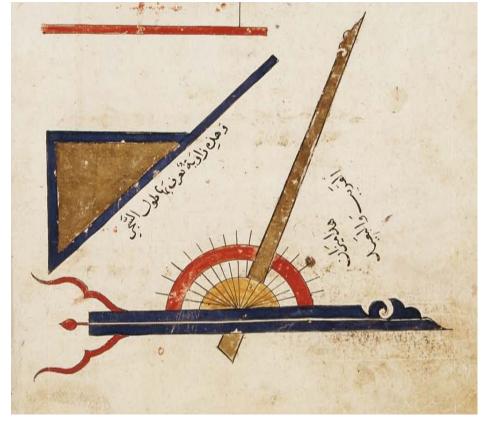



Illustration from:
az-Zardkāš,
al-Anīq fi l-manāǧnīq,
MS Topkapı Sarayı,
Ahmet III, 3469.

[1] Ed. Aleppo, op. cit., p. 48–49.

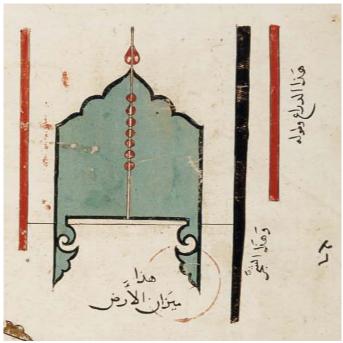



Illustration from:
az-Zardkāš, *al-Anīq*,
MS Topkapı Sarayı,
Ahmed III, 3469.

Ballistic Instrument for levelling

After the counterweight trebuchets of large dimensions had reached a high level of development in the Arab-Islamic world, a special instrument for levelling the ground was used when installing the catapults. The instrument for levelling was called *mīzān al-arḍ*[1].

Our model:
Brass, polished.
Height: 32 cm.
(Inventory No. G 1.15)

[1] az-Zardkāš, *al-Anīq fi l-manāǧnīq*, ed. Aleppo, op. cit., pp. 48–49.

Fortification Towers

In the *Kitāb al-Anīq fi l-manāǧnīq*[1] *of* the 8th/14th century there are several illustrations of fortification towers and fortresses. One of these is shown in our model.

[1] Ed. Aleppo, op. cit., pp. 107–118.

Our model:
Wood, lacquered.
75 × 75 × 75 cm.
(Inventory No. G 2.01)

On the right:
3 illustr. from: az-Zardkāš, *al-Anīq*, MS Topkapı Sarayı, Ahmet III, 3469.
Below: 2 illustr. from: Ḥasan ar-Rammāḥ, *K. al-Furūsīya,* MS Paris, Bibl. nat. ar. 2825.

zaḥḥāfa
(Armoured vehicle
with a battering ram)

A report from the early 4th/10th century gives a good insight into military technology, from which it emerges that the Abbasid army used big gun towers in the conquest of the city of Amorium[1] in 213/837. These gun towers consisted of movable trebuchets (*manǧanīq*) on wheeled gun carriages (*karāsī taḥtahā ʿaǧal*)[2] and were called *dabbāba*.[3]

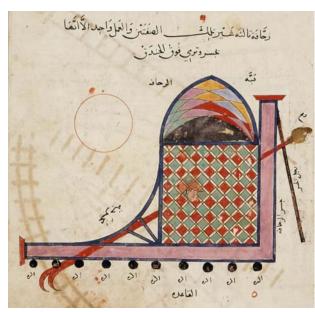



Fig. extraite de: az-Zardkāš, *al-Anīq*, MS Topkapı Sarayı, Ahmet III, 3469.

[1] Today Asar Kale, a place in ruins, south-west of Ankara, v. M. Canard in: Encyclopaedia of Islam, New Edition, vol. 1, 1960, p. 499.
[2] aṭ-Ṭabarī, *Taʾrīḫ*, ed. de Goeje, 3rd series, vol. 2, p. 1248; K. Huuri, *Zur Geschichte des mittelalterlichen Geschützwesens*, op. cit., p. 152.
[3] K. Huuri, op. cit., p. 152.

In this connection it should be noted that a moveable battering ram is depicted in a relief which can be dated as far back as 880-865 BC from Nimrud near Nineveh.[4]

The question of the various stages of development of this piece of war machinery in the Islamic world has not yet been examined. A fairly advanced form of battering ram, called *zaḥḥāfa*, is to be found in the *al-Anīq fī l-manāǧnīq*[5] from the 8th/14th century. It was used for breaking open the gates and walls of fortresses. The battering ram consisted of a covered internal space which was almost always protected against projectiles and incendiary mixtures; inside the space there was an operating team which pushed an enormous iron ram in continuous rhythm against the gate or the wall until it broke down. The extant illustration makes it clear that the battering ram was completely armoured. It contained a foldable bridge which was fastened with hinges in the front at the bottom plate; like a bridge for crossing moats, this too could be let down by means of iron chains.

A great similarity with this type of battering ram can be seen in the two following illustrations from the manuscript in the Bayerische Staatsbibliothek, Munich, cod. germ. 734:[6]

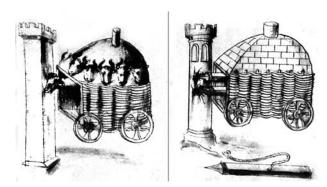



Illustration from V. Schmidtchen, *Mittelalterliche Kriegsmaschinen*, op. cit., p. 152, Ill. 21.

[4] v. Franz M. Feldhaus, *Die Technik. Ein Lexikon* ..., op. cit., p. 1318; J. Würschmidt, *Kriegsinstrumente im Altertum und Mittelalter*, in: Monatshefte für den naturwissenschaftlichen Unterricht aller Schulgattungen (Leipzig and Berlin), 8/1915/256-265, esp. p. 260.
[5] ed. Aleppo, op. cit., p. 122.
[6] V. Schmidtchen, *Mittelalterliche Kriegsmaschinen*, op. cit., p. 152, illustration 21.

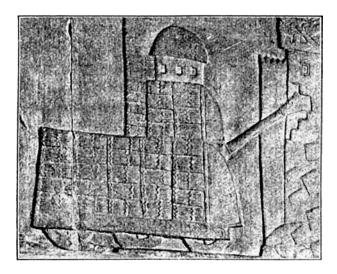



Illustration from J. Würschmidt, *Kriegsinstrumente*, p. 260.

It is remarkable that Giovanni Fontana (1st half of the 15th c.) depicts a moveable battering ram at the beginning of his *Bellicorum instrumentorum liber*.[7] He provides the following caption to the illustration: «War machinery which is called alphasat in Arabic.» I presume that the expression alphasat originated from a distortion of the Arabic term *az-zaḥḥāfa*.

Illustration from Fontana, *Le macchine cifrate*, p. 101.

[7] v. Eugenio Battisti and Guiseppa Saccaro Battisti, *Le macchine cifrate di Giovanni Fontana*, op. cit., p. 101.

Chapter 13

Ancient Artefacts

(Metal, Glass, Ceramics, Wood and Stone)

Cosmetic Utensils

Late Antiquity/Byzantine?
Site where found: Anatolia

Bronze, bone.

(Inventory Nos. J 239–58)

Set of Medical Instruments

Umayyad – early Abbasid (2nd–3rd / 8th–9th c.)

Eight brass artefacts:

1. Curved tweezers
length: 7.4 cm
(Inventory No. J 39–4)

2. Tweezers
length: 8 cm
(Inventory No. J 39–5)

3. Tweezers
length: 7.7 cm
(Inventory No. J 39–6)

4. Tweezers
length: 8 cm
(Inventory No. J 39–7)

5. Tweezers with a hook?
Length: 6 cm
(Inventory No. J 39–8)

6. Scissors
length: 12.4 cm
(Inventory No. J 39–1)

7. V-shaped instrument with two holes
length: 10.6 cm
(Inventory No. J 39–2)

8. Needle
length: 10 cm
(Inventory No. J 39–3)

6 Zweezers/tongs

5th–6th / 11th–12th c.
Nīšāpūr

Bronze
Length: 12.5–21.4 cm.
(Inventory Nos. J 22–27)

Cf. *Khalili Collection*, vol. 12,
No. 364, p. 398.

Spatula

Early Islamic
Northern Anatolia

Bronze, length: 27.6 cm.
(Inventory No. J 64)

Fork

Sassanid or Umayyad
(1st–2nd/7th–8th c.)
Northern Iran (Ṭabaristān)

Bronze, length: 28 cm.
(Inventory No J 61)

Ladle and hook

Abbasid
(2nd–3rd / 8th–9th c.)
Syria

Bronze, length: 53 cm,
with hinge.
(Inventory No. J 63)

1.
Silver.
Length: 20,3 cm.
(Inventory No. J 37)

2.
Copper.
Length: 17,6 cm.
(Inventory No. J 32)

3. (Spatula)
Copper.
Length: 16, cm.
(Inventory No. J 36)

4.
Bronze.
Length: 18,2 cm.
(Inventory No. J 35)

5.
Bronze?
Length: 14,3 cm.
(Inventory No. J 34)

5 Flat Spoons

Ḫorāsān (5th–9th / 11th–15th c.)

Cf. James W. Allen, *Nishapur. Metalwork of the Early Islamic Period,* New York, 1984, p. 90.

1. Measuring Spoon?
Silver.
Length: 26 cm.
(Inventory No. J 38)

2.
Copper.
Length: 18,3 cm.
(Inventory No. J 33)

3.
Cuivre.
Length: 15,5 cm.
Volume: 25 ml.
(Inventory No. J 31)

4. Measuring Spoon?
Copper alloy,
inscription.
Length: 14,5 cm.
Volume: 25 ml.
(Inventory No. J 30)

4 Deep Spoons

Ḫorāsān (5th–9th / 11th–15th c.)

On the question of bronze in Iran in the Islamic period, see J. W. Allan, *Persian Metal Technology 700–1300 AD*, London, Ithaca Press, 1979, pp. 45–55.

Flat Spoon

Sassanid or Umayyad
(1st–2nd/7th–8th c.)
Northern Iran (Ṭabaristān)

Silver.
Length: 19 cm.
(Inventory No. J 62)

Mortar

Salǧūq
6th–7th / 12th–13th c.
Nīšāpūr?

Copper alloy (*batruy*?), red patina.
2 bands of writing (repeatedly: *al-ʿāfiya*, «health») against a floral background, interrupted by medallions with figures.

Diameter: 13 cm.
(Inventory No. J 29)

Published: Sotheby's, *Islamic Works of Art,* London, Avril 1990. Cf. *Khalili Collection*, vol. 12, No. 197, p. 314; no other piece is known which matches this shape. On the copper alloy with lead, zinc and tin, often erroneously referred to as bronze, cf. J. W. Allan, *Persian Metal Technology 700–1300 AD,* p. 53 ff.

Mortar

(Ottoman, 11th/18th c.?)

Common traditional form of a mortar.

Brass,
Diameter: 8 cm.
(Inventory No. J 365)

Cf. *À l'ombre d'Avicenne. La médecine au temps des califes,* p. 136 f.; A. U. Pope, *A Survey of Persian Art,* vol. 13, p. 1280 (Berlin, Staatliche Museen); Ö. Küçükerman, *Maden Döküm Sanatı,* İstanbul, 1994, p. 27.

Small Inkpot (*miḥbara*)

Salǧūq (6th/12th c.)
Nīšāpūr

Copper Alloy,
2 bands with decorative inscriptions.
Traces of ink.
Diameter: 7,5 cm.
(Inventory No. J 40)

Common type of inkpot from Khorasan that can be locked with three pairs of eyelets; while the form of many extant specimens is remarkably constant, the decorations display the entire range of contemporary techniques (besides, of course, openwork): relief casting, engraving, inlay of different coloured metal (or niello and resin); geometrical, floral and figurative, though calligraphy is given preference.

The alloy of brass from copper with the addition of *tūtīyā* (zinc oxide), as well as the lavish use of the latter is described by al-Biruni (362/973–440/1048) in his *K. al-Ǧamāhir fī ma'rifat al-ǧawāhir*. Bronze (i.e. an alloy of copper with zinc and a few additions of other metals) was rarely used in Islamic tradition, more frequently on the other hand a copper alloy that contained much lead; ; cf. R. Ward, *Islamic Metalwork*, London, British Museum Press, 1993, p. 29 f.; cf. also J.W. Allan, *Persian Metal Technology 700–1300 AD*, London, Ithaca Press, 1979, p. 39 ff.; A. Welch, *Calligraphy…* New York 1979, No. 40.

Cf. A.U. Pope, *A Survey of Persian Art*, op. cit., vol. 13, pp. 1311 f. and 1335; Christie's, London, Catalogue *Islamic Art…*, October 1997, No. 237 and October 1999, No. 306. *Masterpieces of Islamic Art in the Hermitage Museum*, Kuwait 1990, No. 29; K.v. Folsach, *Islamic Art: the David Collection,* Copenhagen 1990, Nos. 320–32.

2 Mortars

Egypt, early 15th/late 20th c.

Brass.
Diameter: 13 cm. Height: 19 cm.
Pestle: 23,5 cm.

(Inventory No. J 224)

Brass, coloured metal inlay.
Diameter: 12 cm. Height: 14,5 cm.
Pestle: 22 cm.

(Inventory No. J 225)

3 Bowls

Ottoman

Copper covered with zinc.
Diameter: 7,5 cm.
(Inventory No. J 234–36)

3 Steel Implements for Ignition

for producing sparks

Safavid
(11th / 17th c.)

Steel produced in a forge.
Length: 12,2–15 cm.
(Inventory No. J 57 - 59)

Glass Cutter

Safavid
(11th / 17th c.)

Diamond, set in steel.
Agate handle.
Length: 9,3 cm.
(Inventory No. J 60)

Seal

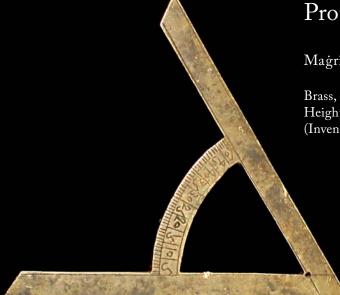
Seljukid (6th / 12th c.)
Nīšāpūr

Bronze?, Hexagram stamp.
Diameter: 1,6 cm.
(Inventory No. J 55)

Cf. James W. Allan, *Nishapur*, New York 1984, p. 72
(Metropolitan Museum 39.40.135).

Cupping glasses

Maġrib, older.

Brass, soldered.
Height: 9,6 cm.
(Inventory No.s J 90–1 and –2)

Cf. *À l'ombre d'Avicenne. La médecine au temps des califes,* op. cit., p. 293.

Protractor

Maġrib (?), older.

Brass, engraved, 50° scale.
Height: 11,2 cm.
(Inventory No. J 91)

Plumbline with spool

Seljukid (6th / 12th c.)
Eastern Anatolia

Bronze?
Length of the bob: 16,7 cm, width of the spool: 8,3 cm.
(Inventory No. J 65)

Cf. Önder Küçükerman, *Maden Döküm Sanatı*, op. cit., p. 40.

2 Dental Forceps?

Age and provenance unknown.

Steel, length: 16 and 17cm.
(Inventory Nos. J 93 and 94)

Wick Snuffer

Safavid
(11th / 17th c.)
Iran

Steel.
Length: 16,5 cm.
(Inventory No. J 28)

3 Fish hooks

Said to be early Islamic
Southern Iran

Bronze?
Length: 33–43 mm.
(Inventory Nos. J 84–1, 2 and 3)

2 Small Brass Weiging Balances:
1. Length of the beam: 11 cm, ∅ of the pans: 7,5 cm.
2. Length of the beam: 17 cm, ∅ of the pans: 6,5 cm.

9 round weights:
1, 3, 5, 7, 12, 16, 21, 45, 92 g.
6 square weights: 0,3–1,6 g.
Tweezers, steel, length: 10,5 cm.

Golsmith's Balance Kit

Qādjār (13th / 19th c.)
Iṣfahān

Box with incised slots.
Dimensions: 23,5 × 14,5 × 4,5 cm.
(Inventory No. J 88)

Cf. *Khalili Collection,* vol. 12, No. 380, p. 404.

Golsmith's Balance Kit

Ottoman?

Box with incised slots, 12,5 × 7,3 × 2,2 cm.
(Inventory No. J 233)

9 Weights

Anatolia?

Brass.
Diameter: 56–160 mm.
(Inventory No. J 237–1 à 237–9)

6 Weights

Age and provenance unknown

Copper alloy.
Diameter: 16–64 mm.
(Inventory No. J 238–1 à 238–6)

9 Weights

ʿAbbāsid?

Copper alloy.
Diameter: 15-25 mm.
14, 26, 26, 28, 28, 29, 29, 30, 57 g.
(Inventory Nos. J 86, 1–9)

Cf. J.W. Allan, *Nishapur*, p. 90 f.

Beaker with Foot

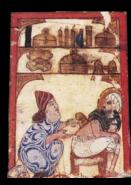
(3rd/9th-15th/11th c.)
Nīšāpūr

Greenish glass with fused decorative threds, repaired.
Height: 12,5 cm.
(Inventory No. J 21)

Cf. *Islamische Kunst* (= Berlin, Museum für Islamische Kunst, Catalogue), vol 1, *Glas*, No. 136; J. Kröger, *Nishapur*, No. 152 (5th/11th c.), similar applications on No. 160.

Lamp

Umayyad?
Syria

Free-blown, reenish glass; sintered,
otherweise undamaged.
allegedly be part of a 6-armed poly-chandelier.
Height: 8 cm.
(Inventory No. J 20)

Cf. Berlin, Museum für Islamische Kunst, Catalogue, vol. 1, *Glas,* No. 13. This type of lamp with a free-floating wick was probably a tradition of Late Antiquity, see Chr. Clairmont, *Benaki Museum. Catalogue of Ancient and Islamic Glass,* Athens 1977, Nos. 91–93.

2 Cupping glasses?

3rd/9th - 4th/10th c.
Nīšāpūr

Green glas, blown with the sucking pipe added on.
Diameter: 4,5 et 3,5 cm.
(Inventory No. J 03 et 05)

al-Ḥarīrī, *Maqāmāt*,
MS Leningrad, fol. 165[a]

Cf. Berlin, Museum für Islamische Kunst, Catalogue, tome 1, *Glas,* Nos. 14–15; Qaddoumi, *La variété dans l'unité,* Kuwait 1987, p. 108; *Khalili Collection,* vol. 12–1, p. 42 f.; *À l'ombre d'Avicenne. La médecine au temps des califes,* p. 168; Chr. Clairmont, *Benaki Museum. Catalogue of Ancient and Islamic Glass,* No. 387; Sotheby's Catalogue, *Islamic Works of Art,* London 10th–11th octobre 1990, No. 45; A. v. Saldern, *Glassammlung Hentrich: Antike und Islam,* Düsseldorf 1974, No. 236 (Syria 2nd–3rd c.); J. Kröger, *Nishapur,* No. 239-243 (3rd/9th–5th/11th c.).

Funnel?

Early Abbassid?
Syria

Greenish glass with bubbles,
Undamaged, apparently there are no comparable pieces.
Length: 27 cm.
(Inventory No. J 01)

Cf. Science Museum, London: No. A79640, A79571, A638600, A6073.

Funnel

$3^{rd}/9^{th}$–$4^{th}/10^{th}$ c.
Nīšāpūr

Greenish glass, spout slightly damaged.
Height: 10 cm.
(Inventory No. J 04)

We do not know of any other comparable piece.

Cupping glass?

3rd/9th–4th/10th c.
Nīšāpūr

Blue glass, spout broken off.
Longueur : 9 cm.
(Inventory No. J 02)

Cf. Berlin, Museum für Islamische Kunst, Catalogue, vol. 1, *Glas,* No. 15, with most of the spout preserved.

3 Small pots and a small bottle

3rd/9th–4th/10th c. , Nīšāpūr ?

Colourless glass, highly iridescent, on the extreme right: pot with fused decoration,
Height: 5, 3, 4,5 and 3,5 cm.
(Inventory No. J 09, 10, 11, 12)

Cf. Berlin, Museum für Islamische Kunst, Catalogue, vol. 1, *Glas,* No. 25, 92–94, 164–165; *À l'ombre d'Avicenne. La médecine au temps des califes,* No. 150; *Benaki Museum. Catalogue of Ancient and Islamic Glass,* op. cit., No. 274, 311; all are considered to be from the Levant; J. Kröger, *Nishapur,* op. cit., No. 42 and 100 3rd/9th–4th/10th c.).

Small Ink Bottle

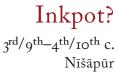
$3^{rd}/9^{th}$–$4^{th}/10^{th}$ c. ,
Nīšāpūr?

Green glass, mould-blown.
Height: 8 cm.
(Inventory No. J 15)

Very similar: A. v. Saldern, *Glassammlung Hentrich: Antike und Islam,* No. 397 («Proche-Orient, 6^{th}–8^{nd} c.?»); Iran Bastan Museum, Téhéran, n° 6849: «Persia, 9^{th}–10^{th} c.» (voir *The Arts of Islam,* Hayward Gallery: The Arts Council of Great Britain, 1976, n° 118); Berlin, Museum für Islamische Kunst, Catalogue, vol. 1, *Glas,* No. 90, with additional literature.

Lamp

Early Islamic
Western Anatolia

Greenish glass with thick walls.
2 eyelets, broken area in a third one.
Height: 11 cm.
(Inventory No. J 17)

Lamp

Umayyad?
Syria (Aleppo?)

Greenish glass, glued together.
3 eyelets, cylindrical holder for the wick, added on the inside.
The chains of suspension probably not original.
Diameter: 8 cm.
(Inventory No. J 18)

Cf. Berlin, Museum für Islamische Kunst, Catalogue, vol. 1, *Glas,* No. 12, 135; K. v. Folsach, *David Collection,* No. 226 et 227; J. Kröger, *Nishapur,* No. 235 (10th–11th c.).

Inkpot?

3rd/9th–4th/10th c.
Nīšāpūr

Green glass, much erroded.
2 small handles, attached by squeezing.
Diameter: 11 cm.
(Inventory No. J 16)

Cf. *The Arts of Islam*, Hayward Gallery, No. 118 (Derek Hill Coll., «Inkwell of blue glass, Persia 9th–10th c.»); J. Kröger, *Nishapur*, No. 229.

Small Bottle

Umayyad?
Syria?

Yellowish glass with black-brown fusings (‹cowhide› ornament, here triangular).
Height: 12 cm.
(Inventory No. J 14)

Cf. A. v. Saldern: *Glassammlung Hentrich: Antike und Islam,* op. cit., No. 332 (Irak/Syrie? VII^{e}–IX^{e} s.); Berlin, Museum für Islamische Kunst, Catalogue, op. cit., vol. 1, *Glas,* No. 128, with additional literature. Since this and the following pieces are examples of ancient techniques continued without a break in early Islamic times, dating these is notoriously difficult.

Beaker

3rd/9th–4th/10th c. ?
Nīšāpūr?

Marbled glass, added on handle; excellent condition.
Height: 15 cm.
(Inventory No. J 06)

One of the oldest known forms of glass vessels, commonly called alabastron or vessel for ointments; mostly without a base, as here. Cf. Chr. Clairmont, *Benaki Museum. Ancient and Islamic Glass,* op. cit., No. 388; A. v. Saldern, *Glassammlung Hentrich: Antike und Islam,* op. cit., No. 399 («jug, North-East Iran?, 7th–8th c.»); *Europäisches und außereuropäisches Glas,* Museum für Kunsthandwerk, Frankfurt am Main, 2nd ed., 1980, No. 1 (ancient) with additional literature.

Bottle

$5^{th}/11^{th}$–$6^{th}/12^{th}$ c.
Ḫorāsān

Yellowish glass, mould-blown (optically) with grooves gathered in folds (‹date bottle›).
Height: 22,5 cm.
(Inventory No. J 08)

Cf. A. v. Saldern, *Glassammlung Hentrich: Antike und Islam,* op. cit., No. 45 and 46 (Syria, 1st c.); Chr. Clairmont, *Benaki Museum. Ancient and Islamic Glass,* op. cit. nº 211; Berlin, Museum für Islamische Kunst, op. cit., Catalogue, vol. 1, *Glas,* No. 40–46.

Small Bottle

IIIe/IXe–Ve/XIe siècle
Ḫorāsān

Verre vert soufflé-moulé.
Décor de nervures entrecroisées et torsadées (motif ‹bossu›).
En excellent état.
Hauteur: 8,5 cm.
(Inventory No. J 07)

Cf. A. v. Saldern, *Glassammlung Hentrich: Antike und Islam,* nº 41 et 286 («Proche-Orient, VIIIe–Xe s.»); C.-P. Haase et al. (éd.), *Morgenländische Pracht. Islamische Kunst aus deutschem Privatbesitz,* Hambourg 1993, nº 87; *Europäisches und außereuropäisches Glas,* Museum für Kunsthandwerk, Francfort, nº 79 («Perse? VIIIe–Xe s.»); J. Kröger, *Nishapur,* nº 120 et 121 (IVe/Xe–Ve/XIe s.).

Small Bottle

Umayyad?
Syria?

Glas (highly eroded) with fused brown garlands.
Height: 9 cm.
(Inventory No. J 13)

quadruple Pigment Bowl

3rd/9th–4th/10th c.
Nīšāpūr

Stone.
6,5 × 7 × 3 cm.
(Inventory No. J 42)

Multiple bowls for spices, chutneys, sweetmeats etc. are often documented (e.g., *Art islamique dans les collections privées libanaises*, Beirut 1974, No. 36) but mostly of ceramics or metal. According to A. Schopen (oral communication), here it is a container for water colours.

Inkpot?

$6^{th}/12^{th}$–$7^{th}/13^{th}$ c.
Nīšāpūr?

Fritware (fragments not of natural clay, but of a mixture of ground minerals and glass with white clay and potash); monochrome, cobalt blue feldspar glazing.

Diameter: 11 cm.
(Inventory No. J 41)

cf. *Khalili Collection*, op. cit., vol. 9, No. 179–182.

No other specimens comparable in shape.

Example of an important ceramic technology where, primarily by the addition of ground glass, an effect was achieved similar to that of the Sung pottery, which was burnt at high temperatures.

4 Ring Stones

Zand/Qāǧār

($12^{th}/18^{th}$–$13^{th}/19^{th}$ c.)
Iran

Carnelian, pious inscriptions in white lacquer.
Width: 23–28 mm.
(Inventory No. J 75, 77, 78, 79)

Top row:

2 Ring Stones:

On the left:
Zand/Qāǧār

($12^{th}/18^{th}$–$13^{th}/19^{th}$ c.)
Iran

Nephrite, engraved.
Width: 33 mm.
(Inventory No. J 76)

On the right:
Timurid
($9^{th}/15^{th}$ c.)?
Iran

Jade, engraved, apparently with a drill. Well-worn (repolished?); indistinct geometrical Kufi inscription appears as mirror image.
Width: 28 mm.
(Inventory No. J 74)

Bottom row:

2 Stones of Signet Rings

Zand/Qāǧār

($12^{th}/18^{th}$–$13^{th}/19^{th}$ c.)
Iran

Carnelian, engraved.
Width: 17 and 20 mm.
(Inventory No. J 72 and 73)

Cf. *Khalili Collection*, vol. 16, No. 587 (set in a ring).

84 Glass seals

Umayyad and later.
Egypt and other provenances.

Diameter: 9-33 mm.
(Inventory No. J 87 1-84)

Glass with stamped-in inscriptions and patterns. Some Egyptian pieces from the Umayyad era can be dated with the help of the inscriptions[1]; others of bluish, iridescent glass with simple patterns (as made by signet stamps of the type of our (Inventory No. J 55) are probably from Iran.

Such discs were used since the early Umayyad period especially as official seals of medicines or food articles which were made according to norms and weights.
Our earliest specimen that can be dated is from the Director of Finances of Cairo, ʿUbaid Allāh ibn al-Ḥabḥāb (102–116/720–734).

[1] W. Dudzus: *Umayyadische gläserne Gewichte und Eichstempel aus Ägypten*… in: *Aus der Welt der islamischen Kunst,* Festschrift für Ernst Kühnel, Berlin 1957, pp. 274–282.

[2] S.K. Hamarneh and H.A. Awad, *Arabic Glass Seals on Early Eighth-Century Containers For Materia Medica,* in: ʿĀdiyāt Ḥalab, vol III, Aleppo 1977, pp. 32–41.

Amulet?

3rd/9th - 6th/12th c.?
Nīšāpūr?

Calcaire, inscription coufique gravée
li-ṣāḥibihī barakatun min ʿAllāh,
(«Que la bénédiction d'Allāh soit sur son propriétaire»)
and animal figure. Reminiscent of Pre-Islamic seals.
6,4 × 6,4 × 1,5 cm.
(Inventory No. J 52)

Cf. *Khalili Collection*, vol. 12, No. 79 (of metal), very similar: Bibl. nat. de France, Cabinet des médailles, Chab. 2262, in: *À l'ombre d'Avicenne. La médecine au temps des califes,* op. cit., No. 185.

Seal

6th/12th c.?
Nīšāpūr?

Copper alloy, inscription.
3,2 × 3,2 × 0,4 cm.
(Inventory No. J 54)

Width: 16 mm
(Inventory No. J 83)

Width: 34 mm
(Inventory No. J 80)

20 × 20 × 16 mm
(Inventory No. J 81)

10 × 10 × 16 mm
(Inventory No. J 82)

4 Seals

13th/19th c.
Ḫorāsān

Rock crystal, engraved, partly with drillings.

On Islamic crystal in general, cf. R. Pinder-Wilson, *Studies in Islamic Art,* London 1985, pp. 145–150.

4 Weights

Said to be Neo-Babylonian
(-7th c.)
Mesopotamia/Elam

Haematite.
Width: 18–25 mm.
Weight: 4, 5, 7 and 16 g.
(Inventory No. J 85–1 to 85–4)

Weights of polished semi-precious stones were also common in Islamic times; cf. for instance *Khalili Collection*, vol. 12, No. 381 (Mughal India, 13th/19th c.).

Haematite weights,
‹Old Babylonian, 2000–1600 BC,
provenance unknown›,
British Museum, WA 117891–900.

Leather Press-Mould

(3rd/9th-6th/12th c.)
Nīšāpūr

Limestone, engraved, fragment.
7,5 × 10 cm.
(Inventory No. J 51)

Cf. R. Pinder-Wilson, *Stone press-moulds and leatherworking in Khurasan,* dans: *Khalili Collection,* vol. 12, pp. 338–355.

Jeweller's Tool?

(3rd/9th-6th/12th c.)
Nīšāpūr

Limestone, engraved on all the four longitudinal sides with figures with varying shape;
2,8 × 5,4 × 2,1 cm.
(Inventory No. J 47)

Casting Mould?

(3rd/9th-6th/12th c.)
Nīšāpūr

Stone.
7 × 5 × 2,5 cm.
(Inventory No. J 50)

Casting Mould?

(3rd/9th-6th/12th c.)
Nīšāpūr

Stone, engraved on both sides.
9 × 8,5 × 1,1 cm.
(Inventory No. J 46)

Casting Moulds?

(3rd/9th-6th/12th c.)

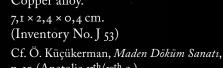
Nīšāpūr

Stone.
9 × 5,5 × 1,5 cm.
(Inventory No. J 43)

Stone.
6,5 × 5 × 1,5 cm.
(Inventory No. J 44)

Stone.
4,5 × 7,2 × 1,5 cm.
(Inventory No. J 45)

Striking Piece
and
3 Casting Moulds
for projectiles

(3rd/9th-6th/12th c.),
Nīšāpūr?

Brass.
3,4 × 1,5 × 0,8 cm.
(Inventory No. J 56)

Copper alloy.
7,1 × 2,4 × 0,4 cm.
(Inventory No. J 53)
Cf. Ö. Küçükerman, *Maden Döküm Sanatı*, p. 10 (Anatolia 13th/19th c.).

Stone.
4,2 × 2,4 × 1,3 cm.
(Inventory No. J 49)

Stone.
6 × 6 × 2,5 cm.
(Inventory No. J 48)

Mould/Model?

12th/18th c. (Zand)
Šīrāz

Stone, engraved, with wax impression.
Diameter: 9,5 cm.
Thickness: 3 cm.
(Inventory No. J 69)

Textile Printing Block

Early 3rd/9th c. (Qāǧār)
Iṣfahān

Wood, incised: Rustam's fight with the dragon.
18 × 20 × 5,5 cm.
(Inventory No. J 66)

Textile Printing Block

Early 3rd/9th c. (Qāǧār)
Iṣfahān

Wood, incised.
15,5 × 19 × 5,5 cm.
(Inventory No. J 67)

Stamp

for goods or cuſtoms

«No. 64» in the name of
Wakīladdaula

Dated [1]137 of the Hegira (=1725)
Kirmānšāh?

Wood, carved.
13 × 8 × 6 cm.
(Inventory No. J 68)

European Glass and Ceramics in Oriental style

Introduction*

In the 19th century European craftsmen realized that the handicrafts produced until then did not meet the requirements of the times. Through the French revolution new strata of society had become the main consumers of handicrafts. Thus the production of industrially made goods at low prices commenced, so as to cope with the larger number of consumers. Private producers as well as state–run enterprises realized that a wide–ranging reform movement had to come about in the field of handicrafts. Only thus could national styles be promoted at a time of emerging nation states. In the course of this development state–run schools for commercial art were founded. For the promotion and display of national styles and of international commerce, World Exhibitions were held from 1851, where not only European countries participated but also countries from the Far and Near East and other parts of the world. Thus the art of Islamic countries was discovered as something particularly exemplary. Art objects from these countries were bought by the many schools of arts and crafts and by the newly established museums of handicrafts. This also led to the emergence of large private collections and collections by business firms. Artists and theorists took note of all the genres of art and studied material technology, systems of decoration and colour design.

Every new theory requires publications in order to propagate and explain the exemplary pieces by select specimens. Thus a market arose for pattern books meant for further education. The most well–known works were those by Christopher Dresser,[1] Adalbert de Beaumont and Eugène Collinot,[2] Albert Racinet[3] and Achille Prisse d'Avennes,[4] which followed up Owen Jones' *Grammar of Ornament*.[5] Ceramics and glassware were the materials which had a great influence on the European market. Ceramic tiles were popular for decorating houses and apartments (Minton Hollins & Co., Tiles, Inventory No. J 360, v. infra, p. 200). However, the products of European firms were not only sold in the European market but found a clientele in the Orient as well. Thus it is known that the Egyptian Khedive gave commissions to the ceramic makers Ulisse Cantagalli (Florence), William de Morgan (London), Vilmos Zsolnay (Pécs) and to the New York glassware artist Louis Comfort Tiffany. The Ottoman Sultans commissioned ceramic artists like Théodore Deck for decorating their palaces and mausoleums, and also their mosques. In 1865 Eugène Collinot (Paris) received a medal of honour from Naṣīraddīn, the Shah of Persia, for his services in the revival of Persian ceramics. Hippolyte Boulenger (Choisy–le–Roi) was consulted for furnishing a part of the Yeni Cami («New Mosque») of Istanbul.

When we look today at European ceramics and glassware with regard to their relationship to the Islamic world, the results are striking: the majority of pieces produced by European companies were executed in the Ottoman style and in forms of decoration derived from it. That was primarily because the floral ornamentations of Ottoman art were captivating due to their exemplary manner of two–dimensional drawing. Moreover, European buyers found them attractive because they [178] could recognise the flowers used in ornamentation (such as roses, hyacinths, carnations and tulips). Such motifs of ornamentation could either be directly adopted or their details could be incorporated into one's own compositions.

* Introduction and the description of the objects by Annette Hagedorn, Berlin; edited at the Institute for the History of Arab–Islamic Science.

[1] *The Art of Decorative Design*, London 1862.

[2] *Recueil de dessins pour l'art et l'industrie*, Paris 1859 and *Encyclopédie des arts décoratifs de l'Orient*, 6 vols., Paris 1883.

[3] *L'ornement polychrome. Recueil historique et pratique*, 2 vols., Paris 1869.

[4] *L'art arabe d'après les monuments du Kaire depuis le VIIe siècle jusqu'à la fin du XVIIIe siècle*, Paris 1869–1877.

[5] *The Grammar of Ornament*, London 1856.

In the collection of the Institute for the History of Arab–Islamic Science, there are examples of the basic possibilities of transfer of the art forms of the Islamic world to Europe. These will be mentioned here: a plate like the one by Théodore Deck (Inventory No. J 358, see below, p. 198) originated in close proximity to Ottoman ceramics of the 10th/16th and 11th/17th centuries. Ph. J. Brocard produced a copy of Mamlūk glass work (vase J 340, see below, p. 180). In other pieces, only some elements were directly copied from the prototypes, but these were put together in a manner that was the maker's own achievement. Such objects were often used for the didactic purposes of learning from the prototypes, for understanding the principles of their ornamentation in order to be able to create something new on this basis. Significantly, the firm of Lobmeyr mentioned in each case the German translation of the Arabic texts on the underside of their glassware, thus endowing them with an academic character.

What was innovative and decisive for the future of European handicrafts were the technologies newly developed at this time, and these could be developed only because of such an intense encounter with oriental objects (cf. Th. Decker, plate J 361, see below, p. 201; Lobmeyr, various forms: J 343–345, 347 and 349, see below, pp. 184–186, 188, 190).

The third variant of the transfer is documented by specimens, for the ornamentation of which such motifs were borrowed which were traditionally part of the total design in Islamic art, but which were converted here into a free–standing single motif. Thus these were virtually «monumentalized». Such decorations corresponded to the spirit of the period of historicism. An example of this is the goblet by the firm Pfulb & Pottier in the collection of the Institute for the History of Arab–Islamic Science (Inventory No. J 342, see below, p. 183).

In the fourth type of transfer, the craftsman conspicuously drew upon Islamic prototypes, created nevertheless something of his own, such as the vase of the firm of Fritz Heckert (Inventory No. J 348, see below, p. 189) and the vase of the firm De Porceleyne Fles from Delft (Inventory No. J 363, see below, p. 202). These pieces in particular show that the designers had a more profound knowledge of Islamic art. For this they travelled throughout Europe and studied the objects in public and private collections, but they also went to countries of the Islamic world in order to improve their knowledge of the subject. Important pieces in the collection, which show a further advance towards the art of modern times, have their own style even though they show a conspicuous link to Oriental art. In this process, it is striking that the inspiration came not only from the art of the Islamic world but also from that of East Asia. In the case of the specimen from the production of Clément Massier, it is obvious how great an influence Arabic script could have on modern ceramics when it served as a repertoire of abstract patterns, detached from its original meaning (Inventory No. J 364, see below, p. 203). On the other hand, the long–necked vases of the firm of Lobmeyr (Inventory No. J 357–1 and 357–2, see below, p. 197) display influences from the East–Asian area and are very close to art nouveau in their ornamentation.

On the whole, the items of the collection provide examples of the path from direct copying of the prototype during the period of historicism to the new forms of ornamentation which already correspond to the forerunners of art nouveau. They show the importance of the art of the Islamic world and of East Asia for the development of a modern style of ornamentation in European arts and crafts.

Vase
in the form of a hanging mosque lamp

Anonymous, probably from France,
Second half of the 19th c.
Colourless glass, mould–blown.
Enamel painting in blue, red and gold.
Red contour lines.
On the base trademark or the name of the firm ground off.
Height: 23.5 cm; Diameter: 19.5 cm.
(Inventory No. J 339)

The vase follows the common shape and ornamentation of Egyptian mosque lamps of the 8th/14th and early 9th/15th centuries. In this period hundreds of hanging lamps for mosques were commissioned by rulers and members of the nobility in Maml‘k Egypt.[1] Because of the quality of the technique of enamelled glass and gold painting, the mosque lamps had been admired in Europe since the Renaissance. In the 19th century many of the lamps were brought from Egypt to Europe and sold, particularly at the Paris art market. Thus they were included in private collections, but were also sought-after objects of study for the newly emerging arts and crafts museums all over Europe. The lamps were either copied by many European glass manufactories or imitated more or less freely, following the Mamlūk style. In the late 19th century, vases were finally made in the form of mosque lamps with completely new European ornamentation. The ornamentation of the vase can be associated with an original mosque lamp of the Spitzer Collection in Paris, which Pfulb & Pottier could have personally seen at the Paris collection.[2] This hanging lamp was made around 760/1360 in Cairo. Here the external shape was borrowed as also the two bands of writing and the medallions with floral motifs. The ornamentation was altered. The vase is heavily decorated with gold, and at the beginning of the neck a band of quatrefoil blossoms was added in gold. This motif is often also used in the surface design of Mamlūk mosque lamps, though not with a gold background.
Similar mosque lamps were often copied in the 19th century. The well-known and larger glassware producers like Brocard (Paris),[3] Lobmeyr

[1] Gaston Wiet, *Lampes et bouteilles en verre émaillé*, Cairo 1912 (= Catalogue générale du Musée Arabe du Caire).
[2] cf. *La collection Friedrich Spitzer*, vol. 3, Paris 1893.

[3] cf. Hartford, Wadsworth Atheneum (Illustration in: Katharina Morrison McClinton, *Brocard and the Islamic Revival*, in: The Connoisseur 205/1980/278-281, esp. p. 280).

[180] (Vienna),[4] Heckert (Petersdorf),[5] Gallé (Nancy)[6] and Inberton (Paris)[7] stamped their copies with their signatures. But other firms made unsigned specimens as well. Often these reached the art market subsequently as counterfeits. The object described here originally had a trade mark on the base in a circular shape with a surrounding band. However, this signature was ground off at an unknown point of time so that the item could be sold as an original piece.

[4] see above, in the description of the parallel example.
[5] cf. Hirschberg, Kreismuseum, Inventory No. MJG 203/v. photo by the author; illustration in *Schlesisches Glas aus der 2. Hälfte des 19. Jahrhunderts: zur Sammlung schlesischen Glases im Kreismuseum Hirschberg (Riesengebirge)und zur Ausstellung im Haus Schlesien*, Königswinter 1992, Cat. No. 50.
[6] Cf. Nancy, Musée de l'Ecole de Nancy, Inventory No. 171 (illustration in: Doris Moellers, *Der islamische Einfluß auf Glas und Keramik im französischen Historismus*, Frankfurt/Main etc. 1992, Cat. No. 56).
[7] Cf. Kunstmarkt 1998 (illustration in: Auction Catalogue Sotheby's of 13. 7. 1987, lot 272).

Comparable objects in other collections, among many others: Vienna, Österreichisches Museum für angewandte Kunst, Inventory No. Gl. 553 (illustration in: Waltraud Neuwirth, Orientalisierende Gläser, vol. 1: J. & L. Lobmeyr, Vienna 1981, p. 54); Nuremberg, Gewerbemuseum der Landesgewerbeanstalt Bayern, Inventory No. 1623/1 (illustration in: Horst Ludwig, Moscheeampeln und ihre Nachahmungen, in: Weltkulturen und moderne Kunst, Munich 1972, pp. 80-93, esp. p. 83).

Vase

Philippe-Joseph Brocard, Paris
Free-blown,[1] greenish transparent glass.
Enamel painting in red, blue, white and green.
Gold lines within the enamel ornamentation.
On the base signature in red lettering:
Brocard Paris 1869.
Height: 31.8 cm
(Inventory No. J 340)

The egg-shaped body of the vase rises from a low profiled foot-ring and turns, without any transition, into the straight upright neck, which is profiled at its upper end with a pinched ring and terminates with a bowl-like spout.
The vase is decorated with two horizontal bands containing ornaments of tendrils with bifurcating leaves, executed in red, blue and green enamel. The broader lower band on the body of the vase is interspersed with three medallions on a white background; its ornamentation also consists of tendrils with bifurcating leaves. This motif had arisen in a succession of stages of development since Late Antiquity and was incorporated into Islamic art. It was employed in the entire area of the Islamic world as an ornament in architecture, in book illumination as well as in the ornamentation of many types of applied art.

[181] From the medallions on the body plant motifs emerge which terminate in stylized animal heads. Such motifs had been developed since the 5th/11th century in Seljuk art and had belonged since that time to the repertoire of ornamentation of all genres of Islamic art.
The vase is a copy of a long-necked Mamlūk vase of the 8th/14th century.[2] At the time when Brocard made his copy, this Mamlūk vase belonged to the large art collection of Baron Edmond de Rothschild (1827-1905) in Paris.[3] While visiting the collection, Brocard probably noticed the vase.
Brocard's vase is in its shape a true copy of the Mamlūk model. The ornamentation also follows the original in its structure. But Brocard changed the elements of the ornamentation by simplifying the line-work of the plant motifs within the ornament bands and medallions. An identical piece (but without the signature) was acquired for the Österreichisches Museum für angewandte Kunst at the World Exhibition of Vienna in 1873.[4] Since the vase in the collection with which we are dealing here was produced earlier in 1869, it follows that Brocard, once he had found suitable prototypes, copied them for many years. Whether the manufacture of pieces without signature allows the conclusion that Brocard glassware was either given as presents or sold by some of his customers as genuine Oriental glassware cannot be established, but is conceivable. In some important glassware collections in museums or in private possession such glassware as the one discussed here was assessed as genuine medieval glassware. Such glassware was also in the collection of Baron Edmond de Rothschild.

[1] K. Morrison McClinton, *Brocard and the Islamic Revival*, op. cit., p. 280.
[2] Carl Johan Lamm, *Mittelalterliche Gläser und Steinschnittarbeiten aus dem Nahen Osten*, 2 vols., Berlin 1929, plate 115, No. 14; Gaston Migeon, *Arts plastiques et industriels*, Paris 1927 (= Manuel d'art musulman, vol. 2); Ernst Kühnel, *Die Arabeske. Sinn und Wandlung eines Ornaments*, Wiesbaden 1949, pp. 223-227.
[3] Annette Hagedorn, *Die orientalisierenden Gläser der Firma Fritz Heckert im europäischen Kontext*, in: Mergl, Jan (ed), *Böhmisches Glas – Phänomen der mitteleuropäischen Kultur des 19. und frühen 20. Jahrhunderts*, Passau 1995 (= Schriften des Passauer Glasmuseums, vol. 1), pp. 84-89, esp. pp. 86 ff.; auction catalogue Christie's London 14. 10. 2000, p. 46.
4 Inventory No. Gl 1052; W. Neuwirth, *Orientalisierende Gläser*, op. cit., illustration 36.

Bowl

Philippe-Joseph Brocard
Free-blown,[1] colourless glass.
Enamel painting in red, blue, white and green. Within the enamel ornamentation, some decorative elements are executed in gold.
On the base signature in red lettering:
J. Brocard, Meudon[2] (1867 and later).
Diameter: 20.5 cm; height: 11.5 cm.
(Inventory No. J 341)

Without a foot ring, the bowl rises, protruding a little, beyond that up to a vertical strip; the wall of the bowl goes up steeply, drawn inwards. The upper end is formed by a narrow, vertical strip as well as a narrow, profiled rim of the mouth.

With this bowl Brocard drew upon Syrian metalwork of the 8th/14th century, without copying these outright.[3] Although in the case of this vessel he was inclined towards a common bowl shape used frequently in Syria and Egypt, he changed the Islamic ornamentation in a supposedly «improved Oriental style» (an expression popular in the 19th century). In the Islamic art of previous centuries the overlapping of ornamentation motifs like medallions and cartouches was unusual. These were placed next to each other and only interlinked by encircling rims. Multiple layers occurred only in the decoration of individual segments of facets. An interweaving such as Brocard used it in this piece was sought after and used only in Spanish-Moorish art. Good examples [183] of this are the stucco decorations of the Alhambra. In his *Grammar of Ornaments*

[1] K. Morrison McClinton, *Brocard and the Islamic Revival*, op. cit., p. 280.
[2] South-east of Paris. Here, in an ancillary building of the castle, Madame Pompadour established in 1756 the factory for refined glass, «Cristalleries des Sèvres». After her death, her brother continued the factory under the name «Royales de Sèvres». In 1870 the firm became the property of Alfred Landier and Charles Haudaille. The signature is meant to show that J. Brocard also worked at Meudon.
[3] A comparable piece for the shape is a water basin from the 8th/14th century from Syria/Egypt (Berlin, Museum für Islamische Kunst, Inventory No. I.921; see Klaus Brisch (ed.), *Islamische Kunst*, Mainz 1985).

(1856), Owen Jones mentioned these ornaments as ideal for surface division and for the colour design. It seems that Brocard closely followed the discussion on the reforms in arts and crafts. Thus he also produced pieces in the Spanish-Moorish style, which was admired by Owen Jones.[1]

Other objects of the firm in other collections:
Comparable pieces: In the same shape but with different ornamentation and larger size: Stuttgart, Württembergisches Landesmuseum, Inventory No. 1981-3.[5] In a somewhat modified form: Paris, private collection.

Glass Goblet

Pfulb & Portier, Paris and Nice
Colourless glass, mould-blown.
Coloured enamel painting on golden background.
On the base, signature in red enamel colour:
A. Pfulb 1877 170 [number of the model].
Height: 25.0 cm.
(Inventory No. J 342)

For the glass goblet of Pfulb & Pottier, a shape was developed that cannot be traced back to any actual prototype. Upon a wide foot, a glass cup was set up which rises almost at right angles from a foot ring. Although the shape of the upper part of the drinking vessel recalls Syrian straight glasses of the second half of the 7th/13th century, it should be noted that the proportions are changed here, as the glass cup was shaped narrower and taller. The decoration consists of five fields in gold, which are extended on to the foot and the cup, with enamelled ornamentation motifs. The main motif of the goblet is a medallion of interwoven stars with the terminations rounded up at the top.

Other objects of the Ṭrm in other collections: Warsaw, National Museum, Inventory No. 157. 478 (illustration in: A. Wesenberg and W. Hennig, *Historismus und die Historismen um 1900*, Berlin 1977, p. 99); Limoges, Musée National Adrien Dubouché, Inventory No. V 330, 331 (illustration in: D. Moellers, *Der islamische Einfluß*, op. cit., No. 77).

[1] cf. Frankfurt, Museum für Angewandte Kunst.
[5] Illustration D. Moellers, *Der islamische Einfluß*, op. cit., illustration 15.

Plate

J. & L. Lobmeyr, Vienna (No. 3873)[1]
(Design Johann Machytka and Franz Schmoranz 1878)
Colourless, so-called «crystal glass».[2]
Gold painting, blue enamel painting.
On the base, Lobmeyr monogram in white enamel paint.
Diameter: 38.0 cm.
(Inventory No. J 343)

The ornamentation of the plate consists of 12 pointed oval fields, the edges of which partly intersect with one another in the lower half. The pointed ovals are alternately decorated with blue enamel or gold ornaments. The blue fields are covered with abstract script, which proceeds inwards from the two ends; the patterns incorporate geometrical knots. The gold fields are filled with floral ornamentation constituted by two palmette blossoms, standing one above the other; on the sides there are other fanciful blossoms of gold and blue colour. In the spandrels between the pointed ovals there are similar floral ornaments. The blue ovals are surrounded by ornamentation with script in gold painting.
The centre of the plate is covered by a circular field formed by an ornamentation made up of a six-lobed star. The spandrels at the tips of the star are each intersected by circle-like formations. A script band runs around the field with the text: «Reason is the best foundation and the fear of God the best garment.»[3] The twelve pointed oval fields are framed with the following inscription: «He who says something about a matter that does not concern him hears what he does not like.»[4]

[1] Vienna, Österreichisches Museum für angewandte Kunst, Catalogue of Lobmeyr's work, vol. XV, page P.
[2] Information on a design sketch, Vienna, Österreichisches Museum für angewandte Kunst.
[3] The author wishes to thank Mrs. G. Helmecke (Berlin, Museum für Islamische Kunst) and Professor A. Karoumi (Berlin) for reading the inscriptions and for providing their literal translation. On the design sketch in Vienna, Österreichisches Museum für Angewandte Kunst, Catalogue of Lobmeyr's work, vol. XV, page P, the following (incorrect) translation is given: «Intelligence is the best foundation and the fear of God the most excellent trait of human beings.» On the back of the plate the following (likewise erroneous) translation is given in white enamel paint: «Intelligence is the most powerful support of man and honesty is his best trait.» It is not known who suggested this translation in the 19th century. In both cases instead of *libās* (dress, garment) *an-nās* (human being) was read.
[4] This inscription is translated in the same design sketch as follows: «He who interferes in other people's affairs will suffer for it.»

Plate
in ‹Arab style› (No. 5524)

J. & L. Lobmeyr, Vienna
(design J. Machytka and F. Schmoranz 1878)
Colourless glass.
Gold painting, blue enamel painting.
On the base Lobmeyr monogram in white enamel paint.
Diameter: 29.0 cm.
(Inventory No J 344)

The plate is decorated by a system of two bands of script (on the edge and around the centre) which are connected to each other by four circles which intersect the script friezes. The centre of the plate is covered with a star motif on undecorated glass. The areas between the circles are covered with enamel ornaments of tendrils with bifurcating leaves.
The style of the ornamentation goes back to Mamlūk metal or glass work.[1] Prisse d'Avennes had already reproduced such a plate in his work on the medieval art of Cairo.[2] It is not known whether the large plate described here is copied from an actual original prototype, or whether it is a pastiche of several Mamlūk originals studied by Machytka and Schmoranz. The ornamentation motifs of the script bands and the tendrils of bifurcating leaves were so well known at the time of production of this plate from many pattern books and also from originals preserved in the Kunstgewerbemuseum in Vienna that the designers could choose a combination of motifs and put them together as ornamentation. The combination of the blue and gold colours is known from the Spanish ceramic art of the 15th and 16th centuries and may have inspired the colour design of objects like the plate discussed here. Examples of Spanish ceramics of the 15th and 16th centuries, which were particularly popular in German-speaking countries, were to be found in all museums of arts and crafts.[2] In their designs Machytka and Schmoranz probably tried to combine different styles of the Islamic world in order to improve on the original models. The inscription in the middle of the plate runs as follows in translation: «The power is God's, the only one, the conqueror.»[4] On the edges of the four circular medallions it says twice each: «Save us from hypocrisy!»[5]

[1] Glass: Dish, middle of the 14th c., diameter 21.6 cm (New York, Metropolitan Museum, Bequest of Edward C. Moore, Inventory No. 1891 91.1.1533), illustration in: Stefano Carboni and David Whitehouse, *Glass of the Sultans*, New York etc. 2001, p. 273. Metal: Prisse d'Avennes, *L'art arabe d'après les monuments du Kaire*, see illustration in *The Decorative Art of Arabia*. Prisse d'Avennes. Foreword by Charles Newton, London 1989, plate 84.
[2] Prisse d'Avennes, *L'art arabe d'après les monuments du Kaire*, see illustration in *The Decorative Art of Arabia*, op. cit., pl. 84.
[3] The extensive collection of the Musée de Cluny, Paris, which was studied by all European producers of industrial art in the 19th century, was last published in: Robert Montagut, *El reflejo de Manises: cerámica hispano-moresca del Museo de Cluny de Paris*, Madrid 1996.
[4] A free translation is given on the back of the object in white enamel paint in German: «Gott ist leutseelig. Gott ist gut – rette uns vor der Heuchelei,» which translates as: «God is affable. God is good – save us from hypocrisy.»
[5] The author wishes to thank Mrs. G. Helmecke, Dipl.-phil. (Berlin, Museum für Islamische Kunst) for reading the inscriptions of this object and for the literal translation.

Plate

J. & L. Lobmeyr, Vienna
(Design by J. Machytka and F. Schmoranz 1878/79)
Free-blown, colourless glass.
Gold and enamel painting in blue.
On the base Lobmeyr monogram in white enamel paint.
Diameter: 18.0 cm.
(Inventory No. J 345)

The ornamentation of the plate is structured from elements of the so-called boteh patterns (Persian, written *būtah*, pronounced *bōte*). The boteh pattern is an important motif in Persian art of carpets and textiles. In its shape it recalls the tip of a tree bent to one side, or a drop; the word means bush.
The plate belongs to a group of models, designated as «Arab. decorirt [sic]» on the design sketches.[1]

[1] Vienna, Österreichisches Museum für angewandte Kunst, designs in the Catalogue of Lobmeyr's work, vol. XV. Walter Spiegl, Glas des Historismus, Brunswick 1980, p. 264, classifies an identical plate as «in Persian style». Although some of the design sketches by Machytka and Schmoranz are referred to as «Persian», the designs are different in respect of their floral ornamentation.

Vase

J. & L. Lobmeyr, Vienna
Colourless glass,
Gold painting, enamel painting in light and dark blue.
On the base, Lobmeyr monogram in white enamel paint.
Design ca. 1878.
Height: 13.5 cm; Diameter: 14.5 cm.
(Inventory No. J 346)

Small vase on a broad foot with a cylindrical body, slightly widened in the upper part, which terminates in a wide extended brim.
The ornamentation of the vase followed designs which Machytka and Schmoranz called Persian but without mentioning the prototype.[1] In this vase, the foot was decorated by a tendril with bifurcating leaves, which is interspersed with stylized motifs of leaves. The decoration of the body begins with a tendril with motifs of stylized blossoms. This tendril is repeated as the end of the body with denser foliage. On the body medallions alternate with compositions of leaves and blossoms in gold paint. The medallions are filled with arabesques. They are framed by a band of golden circles. In the areas containing painted leaves and blossoms, some abstract circular rings are added with enclosed pearl-like shapes. The rim of the vase is decorated by a wave-like tendril, filled with rosette blossoms. The special feature of the ornamentation is the juxtaposition of diverse Oriental and European motifs. What is characteristic of the design is, moreover, the fact that the arabesques, inspired by Moorish art,[2] were also executed by the artist in his own manner, since he filled the area symmetrically and with wide intervals in between.

[1] Vienna, Österreichisches Museum für angewandte Kunst, Catalogue of Lobmeyr's work, vol. XV, e.g., folio FF.

[2] On Moorish art, cf. Montagut, *El reflejo de Manises*, loc. cit.

Vase with double handles

J. & L. Lobmeyr, Vienna (probably designed in 1878 by Johann Machytka and Franz Schmoranz).[1]
Free-blown, colourless glass,
Gold and enamel painting in light and dark blue, pastel green, red and yellow.
On the base Lobmeyr monogram in white enamel paint.
Height: 22.5 cm.
(Inventory No. J 347)

The vase belongs to the glassware in oriental style distributed by Lobmeyr. It is related to the series in Arabic style,[2] but no model number is known for this vase. Often Lobmeyr also produced trial specimens as well as items sent as gifts to European and Oriental museums. Such specimens were not meant for sale; they served to demonstrate the ẞrm's potential, and the museums used these gifts as study specimens.
On to a low foot is set the wide body of the vase, which terminates in a profile ring and then continues in the cylindrical neck that goes straight upwards. The vase terminates with a profile ring and a rim at the edge that is made wider towards the outside. Two undecorated handles join the body and the neck.[3] Because of the gold terminals the handles seem to be held by metal supports. The neck and the body are decorated with fields surrounded by golden frames. The surfaces of the body and the neck are structured with fields framed by blue bars with inset pastel green squares. The fields are decorated alternately with shrubs whose stems, rising up in curves, have pastel green stylized leaves and yellow rosette blossoms; or by shrubs with a kind of stylized carnation blossoms on stems from which deep blue leaves are growing. Both types of ornamentation go back to the art of Ottoman ornamentation of the 10th/16th to 12th/18th century.[4]
The foot and the profile rings are decorated with geometrical motifs of ornamentation.
The entire ornamentation consists of images juxtaposed to each other.

[1] The designer team worked from 1878 to 1880 (or longer) for the firm. Among the items mentioned in the archives of Lobmeyr's firm in the Museum für Angewandte Kunst at Vienna there is no design sketch of the vessel discussed here. Therefore it can only be inferred from stylistically similar objects by Machytka and Schmoranz that they were the designers. For comparison, design sketches of glassware of the same shape but with other ornamentation derived from Ottoman art are likewise preserved in the museum mentioned above.
[2] cf. W. Neuwirth, *Orientalisierende Gläser*, op. cit., illustrations, pp. 33, 36, 37, 44. Waltraud Neuwirth, Lobmeyr. *Schöner als Bergkristall*, Vienna 1999, illustrations, pp. 239, 358 ff.
[3] The shape of the vase was executed in at least four different styles of ornamentation. Cf. illustrations in: W. Neuwirth, *Lobmeyr*, op. cit., pp. 239, 358. W. Neuwirth, *Orientalisierende Gläser*, op. cit., illustration 14, Berlin, Kunstgewerbemuseum.

[4] Atasoy, Nurhan and Julian Raby, *Iznik. The Pottery of Ottoman Turkey*, London 1989.

Vase

Fritz Heckert, Petersdorf/Piechowice,
District of Hirschberg/Jelenia Góra
(formerly Silesia, now Poland)
1879/80 up to 1900.
Colourless glass, mould-blown.
Enamel painting in blue, green, mauve,
Gold paint in incised contour lines.
On the base signature in gold:
FH Co 67 [Serial number].
Height: 24.0 cm; diameter of the body of
the vase: 17 cm.
(Inventory No. J 348)

Vase with a circular body and two decorative handles at the neck. The vase is covered all over the available surface with enamel paint in red, blue, yellow, and leaf-green as well as by gold contour lines in a dense, colourful ornamentation.
All elements of the plant motifs are realized in a very flat two-dimensional style. For the decoration of this object Heckert turned to Indo-Persian art for inspiration, whose elements he independently composed into a well-structured system of ornamentation. In the colours used for this vase Heckert obviously followed the theories developed by Owen Jones in his Grammar of Ornament. There Jones emphasized how important it was to use of the three basic colours red, blue and yellow, which could be enriched with secondary colours only in exceptional cases.[1] Here Heckert used a light leaf-green as subdued colour for Ṭlling in the less important motifs. He did the contour lines of the details of the ornaments in gold, in accordance with Jones's instruction: «Where different colours are used against a coloured background, the ornament is differentiated from the background […] with outlines of gold.»[2] This colour scheme is used primarily for the central area.

Further objects of the firm in other collections: Important examples for comparison of Heckert's, even though in completely different shapes, are to be found today in various museums of arts and crafts.[3]

[1] O. Jones, *The Grammar of Ornament*, London 1856, pp. 6-8, preposition [rule] 14-28.
[2] ibid, p. 81. Cf. A Hagedorn, *Die orientalisierenden Gläser der Firma Fritz Heckert*, op. cit., pp. 84 ff.

[3] There is a large collection in the Kreismuseum at Hirschberg. In an exhibition in «Haus Schlesien» (Königswinter) in 1992, 101 objects of Silesian glassware of the 19th and early 20th centuries of the museum (among them 26 Heckert glasses) were on display and catalogued in an accompanying brochure, cf. *Schlesisches Glas* … Königswinter 1992. Important specimens in Islamic style are owned by the Kunstgewerbemuseum, Berlin, v. Barbara Mundt, *Kunsthandwerk und Industrie im Zeitalter der Weltausstellungen*, Berlin 1973 (= Kataloge des Kunstgewerbemuseums, Berlin, vol. 6), Cat. Nos. 70, 71, 72.

Vase with double handles

J. & L. Lobmeyr, Vienna (Design J. Machytka and F. Schmoranz, 1878/79)
Colourless glass,
Gold painting, enamel painting in light blue, black and green.
On the base Lobmeyr monogram in white enamel paint.
Height: 17.5 cm.
(Inventory No. J 349)

On a gold covered foot ring is set a vessel with a flattened spherical body, which is fully covered with rich ornamentation. On both front sides there is, at the centre in each case, a multi-lobed medallion with a flowering shrub of tulip and carnation motifs executed in enamel paint against leaves painted in gold. In the spaces between the medallions carnation motifs were placed in different colour combinations. The stems are coloured realistically green, the flowers white and light blue. On the neck of the vase, a tendril with similar motifs was painted.
The shoulder is surrounded by a broad band with script which carries four times the words *mā šā' Allāh* («what God wishes»), an exclamation of admiration.[1] The two round handles are affixed on the shoulder band.

[1] On the base appears in white enamel the translation in German «Der Wille Gottes geschehe», which in English means "God's will be done.«

Occasional Table

with two sheets of glass held by a brass frame

Philippe-Joseph Brocard, Paris
Opaque glass.
Enamel painting in blue, light blue, white, red, green.
On the edge of the lower sheet, signature in red lettering: Brocard 1876 achat.
Total height: 78.0 cm.
(Inventory No. J 350)

Each of the two sheets with a curved twelve-lobed outline is decorated with a ring of medallions, consisting of eight circular forms, with two different types of patterns alternating with each other. In the middle of each sheet, parallel to the outline of the sheet, there is a curved twelve-lobed cartouche filled with arabesques.
The ornamentation elements of abstract plant motifs, which appear to be Arabic, are situated within a style of decoration which is selected from motifs of Ottoman Iznik ceramics of the 9th/15th-10th/16th centuries. The most striking elements of this decorative composition are the various fanciful flowers which grow on swinging stems with rich foliage. Parts of the foliage are leaves corresponding to the Ottoman sāz motif.
This unusual table, for which so far no comparable specimens are known, shows how large the variety of forms was which Brocard could supply to his customers.

Cylindrical Jug
with Handle

J. & L. Lobmeyr, Vienna, around 1875
Free-blown, colourless glass.
Gold coating, enamel painting in blue, white.
On the base Lobmeyr monogram
in white enamel paint.
Height: 15.0 cm
(Inventory No. J 351)

The jug follows a form which had been developed since the 16th century in German-speaking areas and is called a ‹Humpen›, i.e. tankard.[1] The ornamentation in the lower part of the jug consists of multi-lobed arches filled with floral elements. Although the jug reveals its origin in the period of historicism, it draws attention to the possibilities that existed to deviate from exuberant ornamentation and to decorate very plainly.[2]

[1] cf. Hugh Tait, *European: Middle Ages to 1862*, in: Masterpieces of Glass, London: British Museum 1968, pp. 127–192, esp. pp. 160, 167.
[2] cf. B. Mundt, *Kunsthandwerk und Industrie im Zeitalter der Weltausstellungen*, op. cit., no pagination, New Renaissance.

Vase

J. & L. Lobmeyr, Vienna, design ca. 1880
Colourless glass.
Gold painting, enamel painting in light blue and ultramarine, white.
On the base Lobmeyr monogram in white enamel paint.
Height: 23.0 cm.
(Inventory No. J 352)

The vase with retracted foot, protruding body and funnel-shaped neck is decorated with a combination of motifs of varying provenance. The body of the vase and the neck are covered with a composition of multi-lobed medallions into which quatrefoils are inserted that are open at the lower part. Four bands of ornamentation encircle the vase. The friezes on the foot of the vase and on the transitional zone from body to neck are antique geometrical motifs: on the foot, intersecting hexagons which are open on the top and into which two gable forms are inserted. On the neck a meandering motif was added. The frieze on the body of the vase shows a tendril with bifurcating leaves, on the neck there is a frieze of similar tendrils. The motifs of this vase are such that could be copied from pattern books. Each motif leads a life of its own, there is no connection between the different registers of patterns. Thus there is no unified concept for the entire vase.

Bowl

Probably J. & L. Lobmeyr,
Vienna, ca.1880, not signed.
Freely blown, colourless glass.
Gold painting, enamel painting
in blue and white.
Height: 10.0 cm;
diameter of the drinking bowl: 10.5 cm.
(Inventory No. J 353)

The shape starts with a wide foot from which a short broad tube rises. Directly under the bowl a profile ring divides the tube, which terminates on the top in a ṭat drinking bowl. The ornamentation of the glass is formed by brown tendrils reminiscent of lustre. The drinking bowl appears as if it was held by a wreath of blue stick-like pattern segments.

The most striking feature of this glass is the verse executed in attractive calligraphy within the two rectangular narrow script friezes (see illustration, second half of the verse). It is the oft-quoted verse from the beginning of a ghazal (*ġazal*) by the Persian poet Ḥāfiz of Šīrāz (d. 792/1390 or 791) which runs in translation thus: «Inspire, cup-bearer, our goblet with the light of wine. Sing, singer: ‹The affairs of the world run according to our wishes›».

Pitcher with two glasses

J. & L. Lobmeyr, Vienna, ca. 1885
Free-blown, medium blue glass.
Incised, gold and silver ornamentation.
On the base incised Lobmeyr monogram.
Height: pitcher: 26 cm; beaker: 10.5 cm.
(Inventory Nos. J 354-1, 354-2, 354-3)

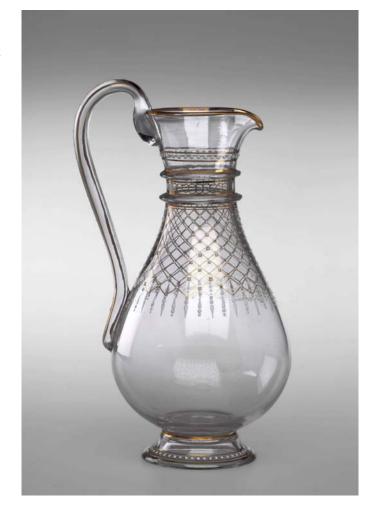
The glassware described here was produced in differently coloured varieties of glass. Glassware in the colours medium blue, yellowish and green are known.
The ornamentation shows upright branches of blossoms in Ṭelds separated by bars. On the pitcher the branches of blossoms grow out of a shrub created by bands. On the beakers the ornamentation is enclosed above and below by decorative strips that go around. On the pitcher these decorative bands run across the foot, above the plant ornamentation on the body as well as on the neck of the vessel.
Glassware like this was also sold in various Oriental countries or presented as diplomatic gifts. We know, for example, of a gift by the firm to the Ottoman Sultan ʿAbdülḥamīd II (r. 1293/1876-1327/1909).[1]

J. & L. Lobmeyr, Vienne, dessin vers 1875

[1] cf. Göksen Sonat, *Bohemian Glassware*, in: Antika (Istanbul) 2/1985/8–10, esp. p. 10.

Vase and Pitcher

with Gold Net Ornamentation

J. & L. Lobmeyr, Vienna, design ca. 1875.
Slightly iridescent, colourless glass,
blown in gold net.
On the base Lobmeyr monogram in gold.

Vase: Height: 14.5 cm.
(Inventory No. J 356)

Pitcher: Height: 29.5 cm.
(Inventory No. J 355)

A bulbous bowl-like body is set up on the retracted and ascending foot of the vase. The short neck terminates in a wide-swinging brim.
In the upper part, the vase is decorated with a gold net with stylized tassel trimmings which give the appearance as if the net was thrown over the body of the vase.
At the upper end a decorative band is formed by a row of compressed circles put together. The foot is decorated by a band of intersecting oval forms. In literature, glassware decorated like this is assigned to the style of Neo-Renaissance. In comparison to similarly decorated glassware of the Lobmeyr Ṭrm, this vase is attractive due to the economy and the stylized elements of ornamentation.[1]
The pitcher belongs to the same series.

[1] W. Neuwirth, *Lobmeyr*, op. cit., p. 377, illustrates examples of the series «brown, green striped with enamel net blown in». Here the tassels of the trimmings are still three–dimensional.

Pair of Matching Vases

J. & L. Lobmeyr, Vienna, end of the 19th c.
Matt glass.
Gold painting, coloured enamel painting.
On the base Lobmeyr monogram
in white enamel paint.
Height: 42.0 cm.
(Inventory Nos. J 357-1, 357-2)

In their basic form the vases correspond to the long-necked vases known from the China of the 18th and 19th centuries.[1] The specimens discussed here consist of a slightly oval body set up on a foot ring. A perfectly circular neck rises vertically from the body of the vase. The foot of the vase is decorated with a band of swirling motifs. Inside this band there is a motif reminiscent of East Asian scripts. The swaying floral decoration on the body consists of small irregularly swirling blossoms on stems with circular leaf formations. The blossoms painted on the vase have slightly curved tips. The neck is adorned with motifs that rise like columns and are juxtaposed geometrically. The motifs seem to be inspired by the East Asian art which reached the European and North American market after the opening up of some Japanese ports after 1854. For this reason in 1867 Owen Jones published a supplementary volume[2] to his *Grammar of Ornament* of 1856 and consequently revised his earlier rejection of East Asian art.
A narrow band of diagonally positioned motifs of bifurcating leaves goes around the upper end of the neck. The individual sections of the vase are separated by five gold bands. Because of these gold bands the tectonics of the vase are completely thrown out of balance. The enamel colours are not painted thickly in a single shade as in other Lobmeyr glassware, but are partially shaded in an artistic manner.

[1] cf. Donald B. Harden, *Masterpieces of Glass*, London 1968, No. 169.
[2] Owen Jones, *Examples of Chinese Ornament selected from Objects in the South Kensington Museum and other Collections*, London 1867.

The ornamentation of these vases is composed of elements of Islamic motifs (at the rim of the neck) and of East Asian motifs. Although their prototypes continue to exist, pieces of glassware like these with their decorations are very close to art nouveau. They are an example of the fact that designers continued to develop their own decorations on the basis of prototypes they had once seen, and now created new types of ornamentation. The ornamentation on the body comes close to the linear swinging floral ornamentation of art nouveau, and the geometrically abstract motifs of the neck of the vase come close to the purist variations of art nouveau ornamentation. Thus the vases show the path traversed by Lobmeyr's into modern times.

Illustration from N. Atasoy and J. Raby, *Iznik*, op. cit., Nos. 404 and 255.

Plate

Théodore Deck, Paris, ca. 1860/65
Fritware.
Polychrome painting under glaze.
On the back engraved signature TH • Deck •
Diameter: 30.5 cm.
(Inventory No. J 358)

The plate was created by Deck in the style of Ottoman Iznik ceramics; he follows examples as they were produced around 970/1560.[1] In the 19th century, examples of these ceramics were much sought-after objects of collections because of their well-balanced ornamentation and their perfect technique of glazing. The ornament field in the mirror of the plate is framed by a decorative band on the rim of the plate. The majority of Ottoman plates and bowls also have ornaments around the rims for the enrichment of the decoration. With its extreme stylization, the ornamentation on this part of the plate created by Deck does not correspond to Ottoman prototypes.[2] Here Deck tried to introduce innovative elements.

Further objects of the Ṭrm in other collections: Ceramics by Théodore Deck in Ottoman style are to be found in many collections in Europe. In Germany important specimens are preserved in Berlin (Kunstgewerbemuseum) and Cologne (Museum für Angewandte Kunst).

[1] cf. plate of the Ex-Adda collection in Rackham. Illustration in: N. Atasoy and J. Raby, *The Pottery of Ottoman Turkey*, op. cit., illustration 404.

[2] cf. the examples in N. Atasoy and J. Raby, op. cit., passim.

Flat square Bowl with retracted corners

Théodore Deck, Paris, ca. 1870
Fritware.
Polychrome painting in blue, red, blue-green, green, purple, black under the glaze.
On the base a red stamp mark TH • Deck •, a relief mark with the portrait of the producer after a design by Fr. Levillain[1] with slightly elevated contour lines, as well as a motif of a dot and a formation of three smaller dots.
Size: 21.5 × 21.5 cm.
(Inventory No. J 359)

The composition is put together from elements of decoration of Turkish Iznik ceramics of the 10th/16th century without directly copying any specific prototype. Instead, Deck put together his own combination of popular motifs of Iznik ceramics here. For his bowl he chose a composition of tulips, carnations, plum blossoms and a flower with six parts that cannot be identified more closely. Against this motif a circular rosette blossom is placed in the centre. The flower shrub follows the Ottoman typology. There too intersections of individual elements of ornamentation occurred somewhat arbitrarily.[2]
The shape of the bowl is unusual in Islamic art and leads us to assume that it was inspired by East Asian art. Because of the square shape the bowl could also be compared with tiles. However, in Ottoman tile ceramics, ornamentation which is complete in itself is unusual because the individual tiles were mostly part of a larger system of ornamentation.
On the whole the bowl with its composition consisting of diverse styles can be rated as a typical example of European historicism of the 19th century, where Deck demonstrates his familiarity with different types of non-European styles.

Further objects of the firm in other collections: ceramics by Théodore Deck with ornamentation derived from Ottoman art are to be found in a number of collections in Europe.
Until now a specimen comparable in shape is unknown. We know, however, that Deck produced wall plates and other decorative ceramics in very diverse styles and shapes.[3]

[1] At some unknown period, Ferdinand Levillain was among the staff of Th. Deck's studio (see Sandor Kuthy, *Albert Anker. Fayencen in Zusammenarbeit mit Théodore Deck*, Zürich 1985, p. 23).

[2] cf. Paris, Louvre, Inventory No. 6643 (illustration 363 in: N. Atasoy and J. Raby, *The Pottery of Ottoman Turkey*, op. cit.).
[3] cf. wall plate in East Asian style, collection Heuser, Hamburg, Munich 1974, Cat. No. 30.

Field of tiles

of four tiles

in a frame
of more recent times

Minton, Hollins and Co.
Stoke on Trent
Pressed clay.
Colours of the glaze in red, blue, yellow, reddish brown, pink, bluish green, leaf-green on white.
On the back pressed-in stamp:
Minton, Hollins & Co.
Patent Tile Works,
Stoke on Trent.
Each tile 20.0 × 20.0 cm.
(Inventory No. J 360)

The field consists of four square tiles. Apparently, the ornamentation follows models from the Islamic world. By the plasticity of the leaves and flowers and also by the strong colours the tiles clearly show their European provenance.
The division of the surface consists of two pointed oval systems of patterns which are filled with palmette and lotus flowers, rosettes and lancet leaves. Although details of the ornamentation are reminiscent of Ottoman and Mughal Indian types of the 10th /16th and the 11th/17th centuries, this new creation is nevertheless successful because of the free treatment of the sources of inspiration and above all because of a totally individual palette of colours.[1]
The design of the tiles could neither be traced within the large archival material of Minton's at Stoke on Trent among the preliminary sketches, nor could it be identified in the sales catalogues preserved. Since the new concept of ornamentation is so successful, it is possible to classify it as an early work by Christopher Dresser when he worked as a designer for Minton's. In his designs Dresser translated the Oriental models into very stylized forms. The example discussed here combines prototypes from Ottoman and Indian art into a unified surface design. The colour design of the tiles is very close to the Mughal Indian examples, and shows how well acquainted English artists and art historians were with the art of that part of the Islamic world. The example from Minton's is a pastiche of different artistic styles of the Islamic world.

[1] Examples of Turkish and Indian art were known to 19th century designers from the above–mentioned (p. 177) pattern books by Jones, Racinet, Collinot/Beaumont, Prisse d'Avennes and Parvillée. However, many of them had also travelled in the Islamic world.

Comparable examples from other collections:
Stoke on Trent, City Museum, Inventory No. 54 P 1954 and Stoke on Trent, archive and museum of Minton's, without Inventory No. The tile has the same decoration but is executed in a different combination of colours.

Two Flat Bowls

with a broad, flattened rim

Théodore Deck, Paris, ca. 1865
Fritware. Polychrome painting under the glaze.
Flat relief ornamentation in the central circular field, three surrounding decorative bands.

1. In dark and light blue, dark purple, red and honey-coloured, two white bands to separate the patterns. On the back an unstructured pattern of lines in the same colours as in the front. Diameter: 22.0 cm.
(Inventory No. J 361)

2. In dark and light blue, two white bands to separate the patterns.
Monochrome back. Diameter: 21.5 cm.
(Inventory No. J 362)

On the base of both pieces the stamp mark THD in dark purple, the letters joined together.
In the ornamentation of the bowls different elements of Mamlūk art of Egypt from the time around 665/1265 were combined with one another. But the band with a free-standing motif of ornamentation on the outer rim was probably an invention of the workshop of Théodore Deck: a leaf is tied in such a way that it can be depicted as standing freely on the stem.
The main element of the plate is a script band in *Nasḫī* style. Here the name of the Mamlūk Sultan as-Sulṭān al-Malik aẓ-Ẓāhir (Baibars, ruled 658/1260-676/1277) is mentioned twice each with the addition «the righteous one, the fighter for the faith», before the inscription concludes in a jumble of letters without any meaning. It seems as if the Deck studio worked on the basis of specific models or illustrations from pattern books. Since until 1865 only the first edition of the work by Beaumont and Collinot was published[1] and since the model for the piece by Deck does not agree with the examples in this work, it is possible that Deck may have worked with originals, in any case he did not work on the basis of this pattern book.[2] In the centre of the plate, in a circular field, there is a tendril made up of vine leaves and grapes. Into the centre of this tendril a free-standing swirling rosette was incorporated. Between the script band and the vine creeper, bands of single leaves were inserted. These leaves are also known from the repertoire of Mamlūk ornamentation, but here they are stylized.
Since Deck's studio also produced samples for the ornamentation and the colour scheme, we may assume that these specimens were such didactic pieces, because of the differing colour scheme.

Comparable piece in other museums:
An identical piece in dark blue and white is to be found in Guebwiller, Musée Florial.

[1] A. Beaumont and E. V. Collinot, *Recueil de dessins pour l'art et l'industrie*, Paris 1859.
[2] The author wishes to thank Stefan Heidemann, Chair of Semitic Philology and Islamic Sciences, University of Jena, for the evaluation of the inscription.

Vase
in the shape of a Persian or a Syrian Ewer

De Porceleyne Fles, Delft (Netherlands), after 1910
Earthenware, lustre ornamentation
(Nieuw Delfts Luster), under glaze colours in white, turquoise. On the base signature in blue and the trademark of the firm in the form of a bottle without spout, under a line: Delft.
Height: 15.0 cm.
(Inventory No. J 363)

In shape and colours, the vase follows Iranian ceramics of the 6th/12th-7th/13th centuries. The spout matches that of a pitcher from the 6th/12th century from Kāšān (Iran).[1] At that time in Kāšān and in other cities of Iran a large number of new ceramic technologies and shapes for vessels were developed, but despite the variety of Iranian vessels of that period no exact parallel piece could be located. It is to be assumed that the designers of the firm of De Porceleyne Fles developed their own decoration from many study objects.

Further pieces of the firm in other collections:
The Hague, Gemeentemuseum (various pieces).
Museum of the firm of De Porcelyne Fles, Delft (various pieces).
Illustrations in Herboren Oriënt. *Islamitischen Nieuw Delfts Aardewerk*, The Hague 1984, passim.

[1] Cf. pitcher, Washington, D. C., Freer Gallery of Art, Inventory No. 09.370 (illustration in: Richard Ettinghausen, *Medieval Near Eastern Ceramics in the Freer Gallery of Art*, Washington 1960, illustration 21 and E. Atil, *Ceramics of the World of Islam*, op. cit., No. 32).

Vase
in the form of a water basin

Clément Massier, Golfe-Juan (near Cannes)
Fritware.
Lustre glaze over an ochre coloured engobe, having a similar lustre glaze.
On the base signature in lustre:
C. M. Golfe Juan A. M. [=Al maritimes] France 1892.
Height: 23.0 cm; diameter 38.0 cm.
(Inventory No. J 364)

The shape of the vase can be derived from the inlaid water basins produced in Iran and Egypt from the 7th/ 13th to the early 9th /15th century.[1] Massier alters the shape in such a way that it looks altogether more elegant, and he achieves a more unified concept of the shape.

The decoration consists of elements that come close to the characters of Arabic script but they do not result in a legible text; rather, the characters give the impression of fragments of words and characters poured onto the vase. Because of the employment of Arabic script, an orientalised ornamentation emerges, which, however, reveals by its completely free use of the prototype models the possibilities for the development of a modern style of ornamentation. Arabic script now became the basis for abstract motifs of ornamentation. The encounter with Arabic script was also made use of by painters of the early 20th century for alienation effects.[2]
The technique of glazing with its combination of lustre applied in two layers had been employed by Massier since the World Exhibition of 1889.[3]

Items of the firm in other collections: Lustre technique: Berlin, Bröhanmuseum, Cat. No. 469 (Karl H. Bröhan, Kunst der Jahrhundertwende und der zwanziger Jahre. *Sammlung Karl H. Bröhan*, Berlin, vol. 2, part 1, Berlin 1976); Collection Heuser, Cat. No. 101 (*Sammlung Heuser* 1976); Oriental Ornamentation: *Sammlung Giorgio Silzer*, Cologne 1976, Illustration 273.

[1] Examples: Egypt, 1290–1310: Paris, Musée du Louvre, Inventory No. 331. In the 19th century in the collection Vasselot, Paris, illustration in: E. Atil, *Renaissance of Islam*, op. cit., p. 74 ff.; Iran, early 15th century: London, Victoria & Albert Museum, Inventory No. 1872–1874, purchased in 1874 from a private collector in London, illustration in: Assadullah Melikian–Chirvani, *Islamic Metalwork from the Iranian World, 8th–18th Century*, London 1982, p. 334.

[2] Artists who converted Arabic script into abstract pictorial idiom are, for example, Paul Klee and Wassily Kandinsky. Cf. Horst Ludwig, *Aspekte zur orientalischen Ornamentik und zur Kunst des 20. Jahrhunderts*, in: Weltkulturen und moderne Kunst, Munich 1972, pp. 122–138, esp. pp. 125–29. Ernst–Gerhard Güse (ed.) *Die Tunisreise*. Klee – Macke – Moilliet, Stuttgart 1982.
[3] K. H. Bröhan, *Kunst der Jahrhundertwende*, op. cit., p. 334.

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